GEOLOGY OF THE EAST HALF OF THE MOUNT HAMILTON QUADRANGLE

S.M. SOLIMAN

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Ferry Building, San Francisco, 1965

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By

SOLIMAN M. SOLIMAN

Department of Geology, Faculty of Sciences

Ain Shams University, Abbassia, Cairo, Egypt

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ILLUSTRATIONS

ABSTRACT

The east half of Mt. Hamilton 15-minute quadrangle (Isabel Valley and Eylar Mountain 7½-minute quadrangles) covers an area of about 120 square miles in the rugged Diablo Range immediately east of Mt. Hamilton. Rocks of the Franciscan formation underlie the entire area, with the exception of small patches of later basalt and Quaternary gravels. The Franciscan rocks in these quadrangles consist largely of clastic sedimentary types. The absence of later cover, the fairly simple structure, the lack of widespread metamorphism, and the moderately good outcrops make the area a good place to study details of Franciscan sedimentation.

Two principal stratigraphic divisions of the Franciscan were recognized in the Isabel-Eylar area. The lower unit consists chiefly of alternating thin beds of fine sandstone, siltstone, and shale. The sandstone is a well-sorted arenite, mature in the sense that its grains consist largely of resistant minerals. The sandstone and siltstone locally show a remarkable development of primary sedimentary structures, such as small-scale cross-bedding, graded bedding, shale flakes, flute casts, and load casts, and slump structures indicating deformation contemporaneous or nearly contemporaneous with deposition. This assemblage of primary structures is best explained by assuming that sedimentation occurred principally as a succession of turbidity currents spreading out over the floor of the depositional basin. The upper part of the lower unit has an abundance of small lenticular masses of coarse-grained sandstone, glaucophanite, and greenstone with minor associated chert. The base of the lower unit is not exposed, but it has a minimum thickness of 7,000 feet.

The upper unit, in contrast to the lower, consists largely of massive, coarse-grained graywacke. Lenses of conglomerate and chert are abundant throughout the unit, and greenstones and glaucophanites are common near its base. Parts of the graywacke show alteration to jadeitite. The top of the unit does not occur in this area, but the thickness represented is at least 3,000 feet.

The Franciscan sediments were supplied to an elongated trough that extended along the continental margin by turbidity currents. Their mineralogic and lithic assemblages indicate the provenance to be mainly from Klamath Mountains suite of rocks with partial contribution from Santa Lucia Mountains.

The greenstone, mostly the typical Franciscan spilite, indicates a series of minor volcanic eruptions accompanying deposition of the upper part of the lower unit and the basal beds of the upper unit. Intrusive serpentine, so common elsewhere in Franciscan areas, is here mainly limited to the edges of two masses lying largely in adjacent quadrangles. Chert accompanying the greenstone may have had a volcanic source; the chert of the upper unit, largely independent of greenstone and containing abundant radiolaria, is more probably of sedimentary origin. Glaucophanite, occurring in isolated lenses, apparently indicates local metamorphism, but it is as difficult to explain here as elsewhere in the Franciscan. Jadeitite is less easy to recognize, but appears to occur chiefly in lenses, but thin sections indicate that jadeite is a more widespread mineral than glaucophane. The associations and composition of the metamorphic rocks make it probable that most of the glaucophanite is metamorphosed greenstone and most of the jadeitite metamorphosed graywacke. Two periods of glaucophanization are suggested by the presence of glaucophanite cobbles in some of the conglomerate.

The general structure of the area is simple, consisting of broad open folds trending roughly northwest. The largest fold exposes the lower unit in its center, with the upper unit to the northeast and southwest. Two zones of conspicuous shearing and numerous dislocations, each followed by a major stream, probably indicate locations of faults with displacements of at least several hundred feet. Many other lines of faulting can be recognized, but individual faults are difficult to trace for any distance. Structures in the lower unit are locally very complex on a small scale, both because of slumping during deposition and later tectonic deformation.

GEOLOGY OF THE EAST HALF OF THE MOUNT HAMILTON QUADRANGLE, CALIFORNIA

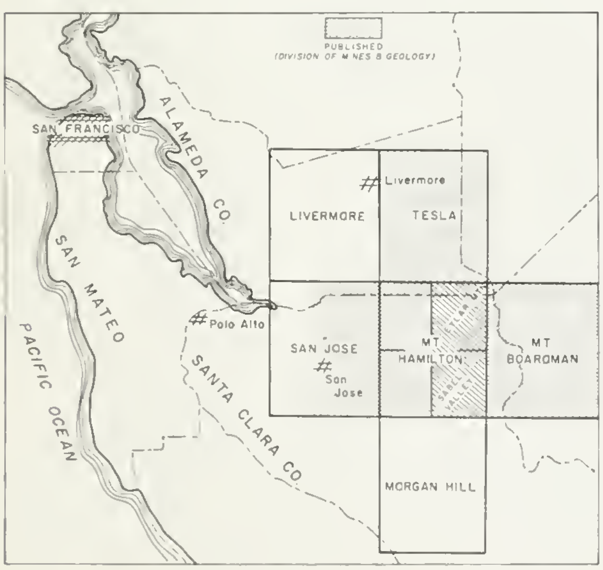
By SOLIMAN M. SOLIMAN

INTRODUCTION

Location and Accessibility. The Isabel Valley and Eylar Mountain 7½ minute quadrangles (Isabel-Eylar area or quadrangles) comprise the eastern half of the Mt. Hamilton 15-minute quadrangle and cover parts of Santa Clara and Alameda Counties, California. Their combined area is about 120 square miles. No towns are located within the area and the nearest ones, San Jose and Livermore, are more than 30 miles from its center.

The area is accessible by the paved but winding Mt. Hamilton Road from San Jose. This road crosses the area from west to east, then turns north and re-enters the area in its northeast corner, and continues northward as Mines Road down Arroyo Mocho to Livermore. Unpaved dirt roads and jeep trails reach other parts of the area but are rare in its rugged parts. Dense vegetation and deep soil conceal bedrock in parts of the area. The absence of younger rocks, the fairly simple structure, the lack of widespread metamorphism, and the moderately good outcrops make the area a good place to study details of Franciscan rocks.

Figure 1 (below). Index map showing location of Isabel Valley and Eylar Mountain 7½-minute quadrangles (east half of Mount Hamilton 15-minute quadrangle), California.



Geomorphology. Elevations in the Isabel-Eylar area range from 4230 feet on Mt. Isabel, to 1200 feet in Arroyo Valle in the northwestern corner of the area. Local relief averages 700-900 feet, with a maximum of about 2000 feet. The ridges are mostly strike ridges, trending roughly northwestward except in the northern part where both topography and structure have an east-west orientation. The generally flat ridge tops provide evidence of uplifted ancient erosional surfaces.

By generalizing the topography, the area can be divided into four main masses separated by major streams. These masses, which reflect the relation of topography to the geology of the area, are:

1) The Isabel-Bollinger highland extends for more than 9 miles northwestward, following the trend of major folds. The surface slopes gently to the west but more steeply toward Isabel Valley. This unit is formed mainly of thick massive sandstone, with volcanic and metamorphic rocks. Mt. Isabel, 4230 feet high, is crowned with chert.

2) The Isabel Valley lowland comprises the eastern half of the Isabel Valley quadrangle, with a very gradual slope eastward 2798 feet to 2162 feet. This area is underlain by thinly bedded sandstone and siltstone.

3) The Valpe area constitutes the western part of the Eylar Mountain quadrangle. It is a comparatively lowland of maximum height 2923 feet, underlain by metamorphic rocks, greenstones and sandstone.

4) The Eylar-Burnt Hill area is a highland formed of thin-bedded sandstone and siltstone in its southern part and chert with coarse-grained sandstone and siltstone in its high northern part. This area is elongated in the direction of major folds.

Creeks and tributary streams in the Isabel-Eylar area, for the most part, are adjusted to the geologic structure. The adjustment is more nearly perfect in areas underlain by the fine sandstone-shale-siltstone sequence than in areas underlain by massive sandstone. These relations can be exemplified by Isabel Creek and Arroyo Valle. Isabel Creek which cuts across the Isabel Valley quadrangle diagonally flows northward

parallel to the strike of the beds and is controlled in most of its path by a zone of pronounced shearing and minor fracturing. In some of its parts, it appears as a misfit stream. A conspicuous feature along its course is Isabel Valley which is a series of interconnected vast flat areas between 2300 ft.–2400 ft. in elevation, covered with brush and a thick soil. Gravel up to 5 ft. or more in thickness covers parts of the valley near the present channel. A similar flat, Horse Valley, is present in the southwestern part of the area. Both flats are crossed by underfit streams. The extent of the flats and the abrupt rise of the surrounding hills favor a hypothesis of fault boundaries to such flat areas.

Arroyo Valle on the other hand shows very little adjustment to geologic structure. Some of the bends in the stream course have such pronounced curvature as to suggest superposition of a meandering stream from an old erosion surface. Remnants of flat surfaces on spurs within the meanders are further evidence for this interpretation.

In general, the area is in the mature stage of dissection. It presents good evidence for rejuvenation before the present time. The evidence can be summarized in the following pionts:

1—Entrenched meonders (mentioned above).
2—Nickpoints, conspicuous in Soupbowl Creek.
3—Erosionol flot surfaces on the tops of hills or the sides of volleys, os exemplified by those along Arroyo Volle.
4—Stream capture.
5—Steep sided canyons which ore widened by block folling ex. Middle Fork Coyote Creek, etc.
6—Misfit creeks, os ports of Isobel Creek.

Use of the term "Franciscan." The term "Franciscan" has been applied to a group of rocks of diverse lithology, including sedimentary rocks, greenstones, chert, glaucophane schists and serpentine, and related rocks that crop out intermittently in a belt along the Coast Ranges of California and southern Oregon. This group of rocks is important in California geology for its extent, its influence on regional structures, and its economic interest. Its exact age range (between late Jurassic and late Cretaceous) has not yet been settled. The very few fossils collected from the sandstones in northern and central California, indicate a short interval (see Irwin, 1957) mainly from Valanginian to Turonian, except for some indications of an Upper Jurassic age (Tithonian).

The historical background for the usage of the term "Franciscan" has been dealt with by previous authors (e.g. Taliaferro, 1943a). Since its introduction by Lawson (1895), the name has been inconsistently applied by different workers, either as a lithologic term for sandstones or for a complex of rock types, or as a stratigraphic rock unit (series, formation, or group). This inconsistency has resulted from a lack of paleontologic or lithologic information to supply stratigraphic control.

In the present work, the term "Franciscan" is generally used for all Mesozoic sandstones and shales of the Coast Ranges that are associated with greenstones, chert and metamorphic rocks (with or without serpentine).

The commonest rock type is the sandstone which has been reported to form up to 75 percent of the Franciscan section. It has been described by Davis (1918a), Lawson (1914) and Taliaferro (1943a). These authors' works and ideas have been quoted and repeated by later investigators without major changes in their methods of study. Quite recently, Bailey and Irwin (1957) tried a different approach by studying the distribution of K-feldspar in the sandstones.

Associated with the sandstones are shales, siltstones, conglomerates, cherts and limestones. No detailed descriptions of the first three have been published. The cherts have been studied by Davis (1918b) and Taliaferro (1943a) and the limestones by Lawson (1914), and others.

The Franciscan glaucophanites and allied metamorphic rocks have attracted considerable attention in recent years—Bloxam, 1956; Borg, 1956; Brothers, 1954; de Roever, 1955a; Switzer, 1951; Taliaferro, 1943a; and others. Despite these investigations, the relation of the metamorphic rocks to other Franciscan rocks, their genesis, and the age of metamorphism are all still matters of dispute.

The greenstones, spilites, keratophyres, and basalts together with the ultrabasic plutonic rocks and serpentine are raw materials for further research.

Previous Work. To the area of Mt. Hamilton, Whitney (1865, p. 44) stated

> It is rendered forbidding by its dryness as well as its roughness and the thick growth of chamisel over a portion of it which renders it extremely unpleasant to traverse, . . ., it will probably remain for an indefinite period what it now is, a barren wilderness.

This statement held true for a long time, and this area, the Isabel-Eylar area, has been left geologically unworked while neighboring areas were studied. This might have been also due to its complexity, and because it is almost entirely composed of Franciscan rocks.

Whitney (1865) mentioned the presence of metarocks and sandstones in the area. Templeton (1913), in his study of the Mt. Hamilton and San Jose quadrangles, reported a thickness of 15,000–20,000 feet for the Franciscan series. Vickery (1924) gave a geologic sketch map of the Mt. Hamilton quadrangle and three neighboring quadrangles, and stated that the geology was mapped by the Stanford Geologic Survey. No data of this work has ever been published.

In later published works, the Isabel-Eylar area has been collectively included in the Franciscan mass of the Diablo Range.

The surrounding geologically mapped quadrangles are:

Mt. Boardmon quadrongle (Moddock, 1955)
Western half of Mt. Hamilton and East half San Jose quadrongle (Crittenden, 1951)
Tesla quadrongle (Huey, 1948)
Morgon Hill quadrangle (portly mapped, unpublished M.Sc. theses, University of Californio, Berkeley).

Acknowledgments. The author is greatly indebted to both Professors Konrad B. Krauskopf and George A. Thompson Jr., under whose supervision this work was conducted. Their discussions, criticisms, and encouragement were a great aid in developing this work.

Thanks are due to Dr. Edgar H. Bailey, (U.S. Geological Survey) for his discussions and for his encouragement. Thin sections (101 in number) of sandstones from northern California submitted by Mr. W. Porter Irwin (U.S. Geological Survey) for this work were of great help. Mr. Salem J. Rice of the California Division of Mines and Geology accompanied the author for several days in the field.

For financial aid, the author expresses his gratitude to the U.S. Educational Foundation (U.S. Government) for granting him a Fulbright Travel Grant and Smith-Mundt Fellowship, and to Ain Shams University, Cairo, Egypt, for granting him a study leave of three years supported by a scholarship. Money from the Shell Grant for Fundamental Research aided part of this work, and funds from the California Division of Mines and Geology aided in completion of the field work and manuscript.

Scope of Work. Of the various Franciscan types of rock, the sandstones have been selected for petrologic study. Work on the problem commenced at the end of October 1956. Good exposures of sandstones in several quadrangles were visited for sampling, and detailed mapping was done in two 7½ minute quadrangles (Isabel Valley quadrangle and Eylar Mountain quadrangle). Samples of Franciscan sandstones were also collected from various places over a large part of central and northern California, from the San Benito quadrangle on the south to the Mendocino National Forest on the north. Three months in the summer of 1957 were devoted to mapping the geology of the Isabel Valley and Eylar Mountain quadrangles. Geologic data were plotted directly on U.S.G.S. topographic maps of a scale 1:24,000, with the aid of aerial photographs of about the same scale.

This Bulletin is largely a revision of Part 1 of the author's Ph.D. dissertation 1958 (see under References). It is concerned only with the geology of the Isabel-Eylar area.

STRATIGRAPHY AND PETROLOGY

Franciscan rocks underlie almost the entire area, the only younger materials being patches of Tertiary basalt and Quaternary gravels along channels of some ravines. Structurally, the Franciscan sequence in this area forms, in a broad sense, the western limb of a major anticlinorium of the Diablo Range. This limb is complicated by folding and faulting.

Franciscan Formotion

Since the introduction of the term "Franciscan" for the enormous group of diverse rocks covering an extensive region in California and southern Oregon, many attempts have been made to subdivide it into smaller units. Such attempts have been successful locally, but in general the units have not been correlated from one area to another.

Lawson (1914, p. 4) recognized five units in the Franciscan "formation" of the San Francisco Peninsula. These are:

Top	Bonita sandstone
	Ingelside red chert
	Marine sandstone
	Sausalito chert
Bottom	Cahil sandstone (including Calero limestone member and some volcanic rocks)

Tolman (1915, p. 45), on the other hand, working from Oak Ridge northwest to Corral Hollow in the Tesla quadrangle, divided the Franciscan "formation" into three units:

Top	Ookridge sandstone, upper "member", slightly metamorphosed sandstone.
	Corral Hollow shale, with massive beds of crumpled and folded cherts and (especially in the vicinity of serpentine intrusions) of lawsonite, chorite and glaucophane bearing schists.
Bottom	Dense blue sandstone with innumeroble quartz veinlets.

Vickery (1924, p. 35) added further details to Tolman's descriptions. He regarded the lower "portion" as quartzitic with a small amount of feldspar. Also, he reported the presence of "low angle cross bedding" in the "Corral Hollow series" which consists of "arkosic sandstones" (although Tolman described these rocks as shales). Taliaferro (1943a), Huey (1948) and Crittenden (1951) claimed the absence of such units in the Corral Hollow section.

Lambert (1923, p. 17), however, working in the area just to the south of this section, divided the Franciscan rocks into three units closely resembling Tolman's but differing in the complete absence of volcanic rocks.

Taliaferro (1943a) presented a four-fold-evolution of the Franciscan-Knoxville geosynclinal deposition. These are (bottom to top):

Lower Franciscan	Arkosic sandstones, volcanic outbursts not common
Upper Franciscan	Widespread volcanism, arkosic sandstone, shale and limestone, maximum development of chert, beginning of instrusion of basic and ultrabasic rocks "accompanied by local formation of pneumatolytic contact rocks"
Upper Franciscan and Lower Knoxville	Coarse and fine clastics, shales more abundant, waning of volcanics and cherts
Knoxville	Fine clastics

In 1955, Irwin and Tatlock (1955, p. 13) reported the presence of three main belts in the Franciscan of

northern California (north of the Healdsburg quadrangle) trending parallel to the coast line. These are:

Western band	Solely clastics
Central band	Containing 25 percent volcanics
Northeast band	Slightly metamorphosed rocks that otherwise are similar to the rocks in the southwest and central bands

To differentiate among these, Bailey and Irwin (1957) studied the frequency of occurrence of K-feldspar in these zones by a method similar to that given by Gabriel and Cox (1929).

Maddock (1955) suggested two divisions in the Franciscan of the Mt. Boardman quadrangle. The lower is fine-grained sandstone with shale, and the upper is coarse clastics. He concluded that these are equivalent to Taliaferro's first and second stages.

In 1958, Rose divided the Franciscan in the Petaluma quadrangle into three formations (A, B, and C) separated by fault contacts:

Bottom	"A"	Meta-graywacke, shale, volcanics, chert, serpentine, etc.
	"B"	Shale
	"C"	Graywacke, shale, volcanics, chert, serpentine, etc.

The Franciscan rocks in the Isabel-Eylar area have been divided into three subdivisions or associations based entirely on lithologic differences. No fossils were found except carbonized wood fragments, radiolaria, and worm tracks. From older to younger these three subdivisions are:

Lower unit	
Lower subunit	Thinly bedded fine-grained sandstone with siltstone and shale, with sedimentary structures, and minor lenses of coarse-grained sandstone
Upper subunit	Lithologically similar to the lower subunit but with a greater number of coarse-grained sandstone lenses, abundant greenstone and localized small chert lenses, abundant metamorphic rocks, and slump structures
Upper unit	Mainly coarse-grained sandstone, siltstone, conglomerate lenses, a few greenstone masses at base, chert lenses more extensive, glaucophanites rare

The first and third of these subdivisions bear some similarities to those given by Tolman (1915) and described by Vickery (1924), but they are more similar to those two divisions given by Maddock (1955).

Of these three lithic subdivisions, the first and second show similarities in their sedimentary characteristics hence they are here grouped and mapped together as one unit and called "Lower unit". The third lithic subdivision, due to its differences from the other two, is here designated as the "Upper unit". The contact between the lower unit and the upper unit is delineated roughly on the geologic map. In the field, however gradational, it is marked by the appearance of coarse conglomerate and the abundance of coarse to medium-grained sandstone. In some places the contact is tectonic.

Lower unit. The lower unit with its two subunits occupies the eastern and central part of the Isabel-Eylar quadrangles, covering about 60% of the entire

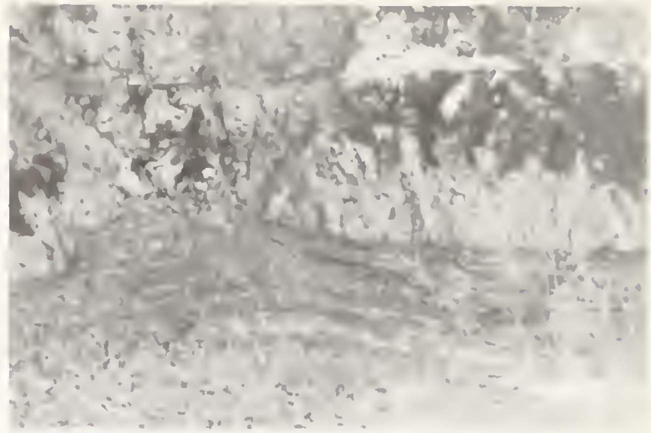


Figure 2. Sequence of thin-bedded fine-grained sandstone, siltstone, and shale, with coarse-grained sandstone lens (middle) (lower unit).

area. It is formed mainly of thinly bedded, hard fine-grained arenite interbedded with siltstone and black shale. Conglomerate was not observed in the lower subdivision of this unit. These strata represent an alternation of sandstone, siltstone and shale. Lenses of coarse-grained sandstone are associated with the upper subunit; they are progressively more abundant toward the top. Primary sedimentary structures such as current bedding, graded bedding, flute and load casts, slump structures, and other sole marks are common and conspicuous. These structures made possible a determination of current direction in a few localities. Greenstones, together with the closely associated small chert lenses and glaucophanites, are abundant toward the top of the lower unit. The structure of this upper part is complicated not only by major pre-consolidation crumpling but also by much tectonic shearing.

The minimum thickness of the lower units as inferred from the structural sections is 7000 feet.

The lower unit can be traced into the adjacent Morgan Hill and Mt. Boardman quadrangles, and the upper subunit is even more widely recognizable in other parts of the Diablo Range. In the San Francisco Peninsula, also, rocks similar to those of the lower unit are mapped as Franciscan. However, the lower unit herein described resembles rocks elsewhere called "Knoxville".

Upper unit. The upper unit occupies two localities in the Isabel-Eylar area, one to the southwest where it overlies the lower unit and the other to the extreme north separated from the top of the lower unit by a zone of complex structure. In contrast to the lower unit, it is formed mainly of thick-bedded massive coarse-grained sandstone of the graywacke suite, with siltstone. Sedimentary structures like those of the lower unit are scarce or absent. Conglomerate lenses occupy different stratigraphic positions but increase in number toward the base of the unit. Greenstones are also present near the contact with the lower unit. Chert lenses, a characteristic feature of this unit, are much thicker

and more extensive than those of the lower unit. The chert also is not limited to the neighborhood of greenstones, as it is in the lower unit. Structurally, the competent upper unit yielded more to large scale, broad folding than to pervasive faulting and shearing as the lower unit did. This is why the upper unit has a more regular structural pattern than the lower.

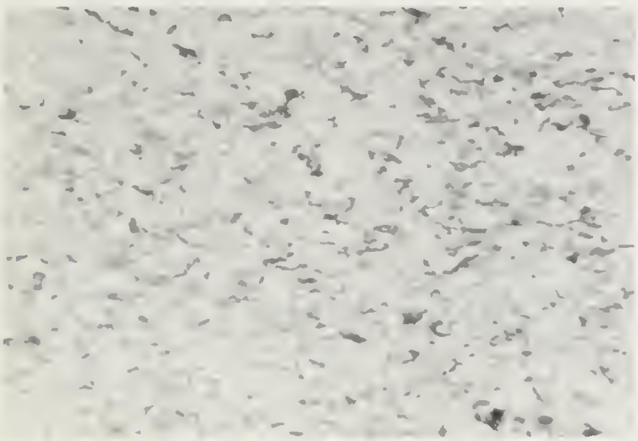


Figure 3. Photomicrograph of fine-grained sandstone, arenite from the lower unit, showing chlorite and mica presenting a recognizable preferred orientation. x32.

The minimum thickness represented in the Isabel-Eylar quadrangles as inferred from structural sections is 3000 feet.

In the Diablo Range, outside the Isabel-Eylar area, the upper unit is more widespread than the lower unit. Many localities in the western half of the Mt. Hamilton, Tesla, Morgan Hill, Gilroy Hot Springs, Quien Sabe, San Benito, Ortigalita, and Mt. Diablo quadrangles show similar lithologic characteristics. Petrographic work gives further confirmation to this correlation.

In the following pages, the petrology of the different rock types in the two units is discussed. To avoid unnecessary repetition they are generally discussed without reference to their place in the stratigraphic section.

Sandstone

Fine-grained sandstone. The fine-grained sandstone is a hard, light to dark grey sandstone constituting a little more than half the total volume of the lower unit. Usually it is in flaggy, fissile or massive beds between 2 inches and 3 feet thick, with interbedded shale and siltstone. The sandstone (specific gravity = 2.64) is well sorted, most of the grains vary in diameter from ¼ mm to 1/16 mm with an average of about ⅛ mm; the finer grained matrix is limited to 4-8 percent.

Most of the grains are approximately equidimensional, but others are elongated, giving a linear fabric to the rock. Of the many grains measured in two thin sections, an average ratio of the shortest and longest dimensions ranges between 1:1.1 to 1:1.7.

Mineralogically, the sandstone consists of quartz, fresh sodic plagioclase (determined by Gilbert and Turner's method, 1949), chlorite, biotite, muscovite, opaque minerals, tourmaline, sphene, and very rare fragments of shale, chert, volcanic rock and quartzite. Their percentages point-counted (Chayes method, 1949) range as follows:

Mineral grains:		Lithic fragments:	
Quartz	33 -60%	Shale	0.5- 7%
Plagioclase	8 -30%	Chert	0.3- 7%
K-Feldspar	0 - 3.5%	Volcanic rock	0 -10%
Mica	2 -12%	Others	2 - 9%
Chlorite	0.5-14%	Matrix	7 -15%
Sphene	0 - 2.5%		
Opaques (ilmenite, pyrite, Fe oxides, etc.)	1 - 3%		

Heavy minerals present are: actinolite, apatite, biotite, chlorite, diopsidic augite, epidote, hornblende, hyacinth, ilmenite, leucoxene, magnetite, pyrite, sphene, tourmaline, zircon. The frequencies of the fine-grained sandstone constituents can be compared with those in other parts of California, namely the Calaveras Reservoir and Eden Valley quadrangles (Table 1).

*Table 1. Examples of frequency of occurrence * of the main detrital constituents in the Franciscan sandstones.*
(Percentages)

	"a"	"b"	"c"	"d"	"e"	"f"	"g"	"h"
Mineral Grains								
Quartz	26	25	29	14	12	13	19	25
Plagioclase	18	20	20	20	11	15	16	20
K-feldspar	1	2	1	—	—	p.		2
Mica	7	5	6	2	3	2	1	2
Chlorite	2	4	3	5	2	6	8	4
Epidote	—	p.	p.	0.5	0.8	p.	4	3.6
Sphene	0.5	1.3	1	p.	—	0.3	0.3	p.
Others †	6	2	2	17	11	7	3	2
Lithic Fragments								
Shale	2.5	1	3	1	4	3	2	3
Chert	11	14	14	18	24	20	11	8
Volcanic Rock	5	6	2	10	24	20	17	10
Others	7	5	4	3	3	6	9	7
Matrix	14	15	15	10	6	8	11	13

"a, b, and c" are sandstone specimens from the Calaveras Reservoir area, Calaveras Reservoir quadrangle.
"d, e, f, g, and h" are sandstone specimens from the Eden Valley quadrangle, northern California. Specimens "d, e, f, and g" are from sandstones associated with greenstone and chert. Specimen "h" is from sandstone associated with no greenstone or chert.
* Percentages were determined by point-counting the grains in the thin sections.
— Absent.
p. Present in a very few grains.
† Including some authigenic minerals.

Coarse-grained sandstone. Coarse-grained sandstone, mostly of the graywacke suite (Pettijohn, 1949, 1957), constitutes about one-third of the Franciscan exposures in the Isabel-Eylar area. It ranges in grain size from medium to coarse. Beds are usually more than 10 feet thick. Generally, the mineral grains are tightly packed, forming a well indurated, massive and impervious rock. In the fresh state, the graywacke (specific gravity = 2.67) is gray or grayish green, on weathered surfaces a blotchy yellowish or brownish-yellow color dominates and the rock is friable. The graywacke contains an abundance of lithic fragments, most of them unabraded shale flakes with chert and volcanic rock fragments. Mineralogically, it is similar to the fine-

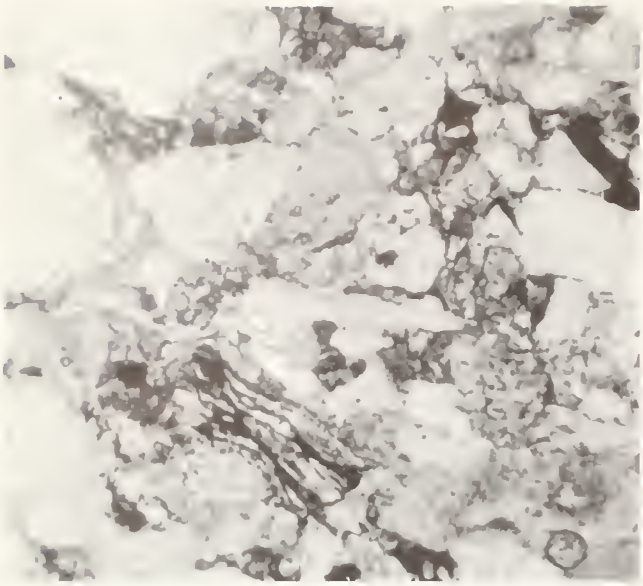


Figure 4 Photomicrograph of graywacke from the upper unit, showing its ill-sorted and polymictic nature, and its partially recrystallized matrix. x32.

grained sandstone. Approximate ranges of abundance are as follows:

Mineral grains:		Lithic fragments:	
Quartz	25 -56%	Shale	1 -12%
Plagioclase (mainly sodic)	8 -33%	Chert	1 -20%
K-feldspar	1 - 9%	Volcanic rock	1 -12%
Mica	2 -17%	Others	0.2- 8%
Chlorite	1 - 6%	Matrix	8 -15%
Epidote	0 - 1.5%		
Sphene	0 - 1.5%		
Apatite	0 - 1.5%		
Opaques (ilmenite, pyrite, Fe Oxides, etc.)	0.5- 4%		

The heavy minerals are: actinolite, apatite, biotite, brown hornblende, chlorite, diopsidic augite, epidote, garnet, green hornblende, gahnite, hypersthene, hyacinth, ilmenite, jadeite, leucoxene, magnetite, piedmontite, sphene, tremolite, tourmaline, zircon. Jadeite is present in almost all specimens analyzed but could not be seen in thin sections. Comparison of abundance of the coarse-grained sandstone constituents with those of other parts of California can be made with the above-mentioned table (Table 1).

In Gilbert's classification (Williams, Turner and Gilbert 1954), much of this coarse-grained sandstone lies near the border-line between graywacke and arenite due to the presence of 8-15 percent matrix. In nearly all cases, the matrix has recrystallized into a finer grained chloritic, sericitic, siliceous mesh that hinders the breaking of such rocks along the grain boundaries.

Shearing of the graywacke is apparent in certain zones and in the neighborhood of some igneous rocks and metamorphic rocks. Bedding schistosity, especially along the interfaces between the coarse- and fine-grained beds, is common. Argillites typically show evidence of slip-movements along closely spaced surfaces and the slip-planes commonly are crenulated on a minute scale. The more rigid sandstone yielded in part by a system of tension fractures. Boudinage structures are found locally. Quartz veins are commonly present in the sandstone and boudins, where they occupy tension fractures and line surfaces of minor shearing. These veins are especially common in zones of structural complexity like that along Colorado Creek. In thin section, microbrecciation and recrystallization of the standstone are recognizable.

Tuffaceous graywacke is present with the coarse-grained graywacke but is not recognizable in hand specimen. One of the thin sections showed partially recrystallized tuffaceous material with gritty, sharply angular grains of quartz and plagioclase.

Related to tuffaceous graywackes are the celadonitic sandstones. Although celadonite is present in very minor amounts as clasts in some of this coarse-grained sandstone, it usually appears to be authigenic, as it occupies the spaces among the detrital grains and partly replaces them. The celadonitic sandstone (specific gravity = 2.66) is present as small masses of deep green color about 20 ft. in maximum diameter, which grade through fainter colors to normal graywacke. These masses are usually tuffaceous. Celadonitic sandstones have not been previously described from the Franciscan rocks.

In thin section, the celadonite is in a cryptocrystalline aggregate with a high birefringence. A tinge of blue color over the green is noticed by rotating the stage of the microscope. The refractive index of the celadonitic material could not be determined with any accuracy due to the fineness of the grains, but generally, it varies between 1.57-1.59, with the deeply colored masses showing the higher refractive indices. These refractive indices would put this celadonitic material between the end members of the celadonite-glauconite group. However, because of the comparatively high refractive indices and the presence of the blue tinge, the material is collectively called celadonite.

In addition to its presence as the groundmass, the celadonite occurs as a replacement of the detrital grains, where it either forms embayments or extends along the cleavage planes of the plagioclase. Commonly string-shaped aggregates are present and show a wavy appearance. Cross-sections of these present a concentric pattern with celadonite bordering quartz cores.

The localization of the celadonitic sandstone and the common association with tuffaceous sandstone suggest the possibility of formation of the celadonite through alteration of glassy volcanic material originally contained in the rock. Celadonite has been previously recognized as an alteration product of volcanic rocks by Hendricks and Ross (1941), and Reinhard and Wenk (1951, p. 40).

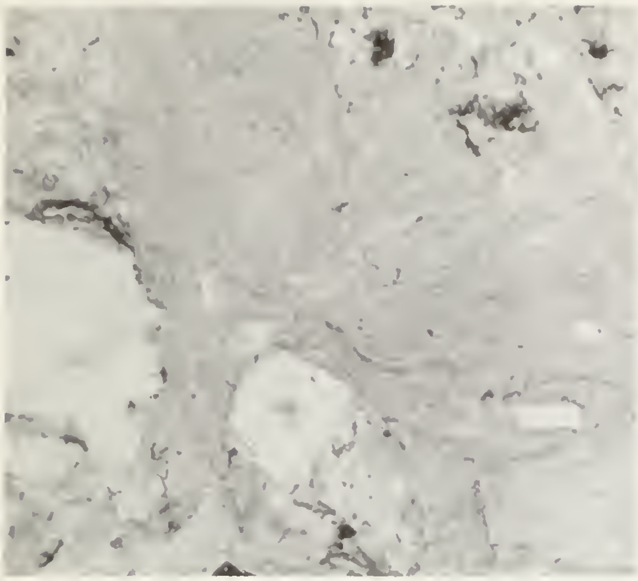


Figure 5. Photomicrograph of celadonitic sandstone showing development of celadonite in the groundmass and replacing some detrital minerals as plagioclase. x32.

Siltstone and Shale

Except for the grain size and a consequent scarcity of rock fragments, siltstones and shales are similar in their constituents to the associated sandstones.

Normal shale is much less abundant than silty shale or siltstone. It is mainly associated with the fine-grained sandstone of the lower unit. The silty shale and siltstone are associated with both the fine-grained and the massive coarse-grained sandstones but are most abundant in the former. Small-scale sedimentary structures, such as current marks, slump structures and sole marks, are common in the siltstone and the fine-grained sandstone. In thin sections and on polished surfaces, fine contortions are recognizable. Pyrite is locally abundant in the black shale.

Fragments of the shale and siltstone are present in the coarse-grained sandstone as well as in the associated conglomerate.

A few carbonate concretions are also present in the shale. They are commonly elongated with the bedding and have a maximum diameter of 10 to 12 inches. Microscopically, the calcite crystals are cloudy, and enclose detrital grains that increase in abundance toward the border of the concretion. No fossils, either micro- or mega-fossils, were found in the concretions.

Conglomerate

The conglomerate forms a very small proportion of the sedimentary section. It is mainly present with the coarse-grained graywacke of the upper unit, in lenses elongated with the general structure of the area. The distribution of the conglomerate lenses is represented on the geologic map; the dimensions of some are slightly exaggerated to facilitate their representation. The longest mass, east of Pyramid Rock, is about 2000 feet long and about 75 feet thick. A few of the beds just under the conglomerate show scouring and sharp contacts, which suggest submarine erosion during the formation of the conglomerate lenses.

Clasts in the conglomerate range from boulders about a foot in diameter to pebbles. In some beds, gradation in size is noticeable, but some entire outcrops show a comparatively small size range. The groundmass is variable in amount and consists of normal sandstone. In some outcrops, it forms nearly the whole bulk of the rock, with the big boulders "floating" in it.

Boulders in the conglomerate represent a wide variety of sedimentary, igneous and metamorphic types. The sandstone and shale boulders in the conglomerate bear great similarities to those of the "Franciscan." The sandstone is fine-grained; and in one instance showed sedimentary structures like those of the lower unit. The chert pebbles are mostly greenish, although reddish chert pebbles are present along Mine Road in the Eylar Mountain quadrangle.

Rounded porphyritic quartz and/or plagioclase keratophyre cobbles and boulders are also present. Some of them are fresh while others show significant weathering apparently inherited from their source. In thin section, the euhedral albitic plagioclase (albite An_4–An_7) phenocrysts are sometimes aggregated to give a glomeroporphyritic texture. The quartz phenocrysts are embayed by the surrounding groundmass formed of small albite laths, microcrystalline quartz, and minor fine-grained white mica. Ilmenite is present as small crystals. When the rock is altered, lawsonite is developed as stout laths in the plagioclase crystals. Keratophyres of similar lithology are described in situ by Kinkel, Hall and Albers (1956) in the Klamath Mountains, also by Maddock (1955) in the Mt. Boardman quadrangle among the Franciscan rocks.

Pebbles of granodiorite, normal granite and albitic granite together with minor amounts of quartz diorite and gabbro are also present. In thin sections, they usually show an abundance of albite and chloritized biotite. Tiny pink garnet crystals were noted in one cobble in pebbly graywacke along the northern part of Isabel Creek.

Serpentine, metamorphic rocks, and quartzite are also found. Glaucophanite pebbles are present in some conglomerate lenses. But whether the glaucophanite is Franciscan or older could not be determined. It is interesting to note that these pebbles occur in beds stratigraphically higher in the Franciscan section than the glaucophanite in the upper subdivision of the lower unit; as mentioned above, shale and fine-grained sandstone cobbles and boulders are also found. But, if the glaucophanite pebbles were derived from the glaucophanite of the lower unit, glaucophanization would

have taken place in more than one stage—one before and another after the deposition of the upper unit.

The conglomerate in shear zones shows elongated and squeezed pebbles.

Chert

Lenses of Franciscan chert are common in the Isabel-Eylar area. With respect to their association, they can be divided into (1) those associated with greenstones, and (2) those associated with sandstones and shales.

Although the two types cannot be easily differentiated, certain distinctive features are recognizable in each.

Chert lenses closely associated with, or included in, greenstones usually are too small to be represented on the geologic map. They are common in the upper part of the lower unit. Commonly, they are greenish-white bands more than two inches thick. The whole lens may be a maximum of 15 feet thick. Detrital minerals are scarce or absent. Microscopically, the chert is made of finely crystaline quartz with occasional tiny rhombohedra of dolomite. Organic structures resembling radiolaria are rarely observed. This scarcity could be attributed either to a lack of much contribution of siliceous skeltons during the formation of these cherts, or to crystallization. In a few instances, poorly preserved colloform structure is noticeable. Many of the chert lenses show the development of metamorphic minerals such as glaucophane, sphene, garnet, chlorite, mica, etc., with relict chert banding.

Chert lenses in the upper unit are not associated with greenstones. Some of them are several tens of feet thick (up to 200 feet, at the base of Pyramid Rock) and very extensive. Groups of closely spaced lenses underlie some of the high ridges, for example Mt. Isabel and Eylar Mountain. Most of the lenses are not easily mappable because exposures are not continuous and because contacts are gradational into siliceous shale. On the geologic map only the larger and more continuous of the chert bodies are distinguished.

The chert consists for the most part of thin beds (1/4″-3″ thick) separated by siliceous shale or sandstone, but some of the bodies are massive. In thin section, the chert is microcrystalline with an abundance of embedded radiolarian skeletons. These are circular or oblong in outline, with tiny protrusions to the outside. When the rock is intensely recrystallized, they appear as faint circular objects enclosing quartz that is coarser grained than the groundmass. Clayey material, fine unidentifiable prismatic crystals and impregnations of manganese and iron minerals are commonly present in this chert, and are more abundant than in the other type of chert. These manganese and

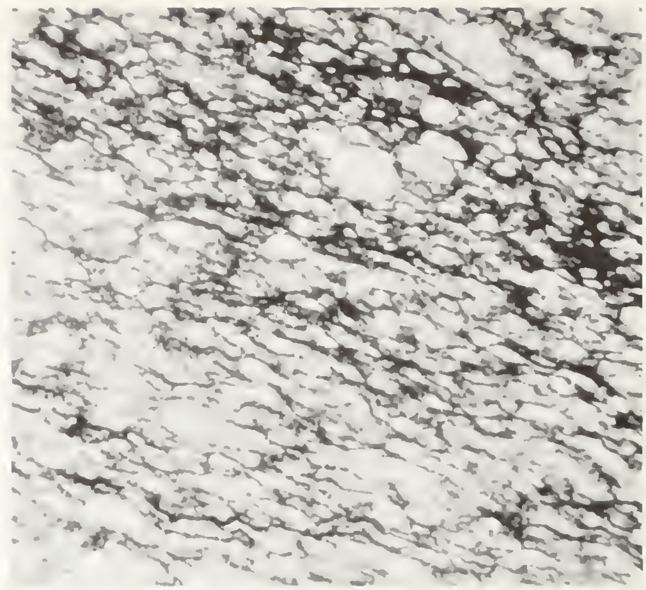


Figure 6. Photomicrograph of radiolarian chert from the upper unit. Radiolarian skeletons are prominent because of iron and manganese oxide impregnation. x32.

iron oxides color the chert black, brown, red, and yellow. More than one period of sillicification is indicated by chert breccia in a differently colored siliceous matrix. The associated siliceous shale, like the chert, has abundant radiolarian skeletons. This radiolarian chert bears similarities to the chert of the Calaveras formation of the Sierra Nevada as described by Taliaferro (1943c).

Recrystallization and shearing of chert masses of this type and the enclosed quartz veinlets are common. Where intense recrystallization has occurred, jadeite and lawsonite are commonly found as metamorphic minerals in the adjacent sandstones.

A better understanding of the attitude and the mode of occurrence of both types of chert in the Isabel-Eylar area can be sought through three main points—theories associating chert with volcanic rocks, current theories on the formation of chert with clastics, and diagenetic processes that affect freshly deposited silica.

The origin of the Franciscan chert has often been ascribed to contemporaneous volcanic activity. This is plausible when the chert is intimately associated with greenstone. Examples were given by Crittenden (1951), Taliaferro (1943a), Briggs (1953). But this origin is less easy to defend for occurrences of chert independent of greenstones. Examples of independent occurrences, besides those found in the Isabel-Eylar area, are given by Taliaferro (1943a) in the Mt. Diablo, Travis (1952) in the Sebastopol quadrangle, and Huey (as shown from his map, 1948) in the Tesla quadrangle.

In recent publications, Krauskopf (1956, 1958) has clarified the processes of deposition of silica.

> "Colloidal silica may be precipitated by evaporation, by cooling, or by addition of electrolytes, but if the solution is at equilibruim, the dissolved silica does not precipitate. Precipitation of dissolved silica may be brought about by organisms, by absorption, by reaction with cations to form silicates and probably by slow approach to equilibrium with a crystalline form of silica" Krauskopf (1958, p. 63).

That organic agencies played an important role in the formation of some cherts in the Isabel-Eylar area, is indicated by the abundance of radiolarian skeletons. These appear as small globules clearly recognizable if the chert has been impregnated with iron and manganese oxides and hydroxides. Their outlines survive even considerable deformation, except for apparent elongation in the direction of shearing. Radiolaria are particularly abundant in cherts of the upper unit, where greenstones are practically absent.

The scarcity of radiolarian skeletons in the chert masses associated with volcanic rocks may indicate that silica added to sea water during the volcanic eruptions (either by hot springs or by reaction of sea water with hot lava) was inorganically deposited in the vicinity of the vent. Here deposition could be relatively fast. This can account for the very localized occurrences of these lenses, their close association with volcanic rocks, their colloform structure, and the insignificant dilution with clastics. The efficacy of inorganic processes to remove silica from sea water is indicated by the work of Bien, Contois, and Thomas (1958) on the precipitation of soluble silica from Mississippi River water as it enters the Gulf of Mexico.

A possible indication of how slowly the radiolarian chert was deposited is the estimate of 0.5-0.7 cm/1000 years for diatomaceous ooze in the Pacific Ocean (Kuenen, 1950, p. 378). If such a rate was maintained during the deposition of a radiolarian chert lens, say 100 feet thick, 6,000,000 years would be required for the formation of the lens. Even a rate ten times greater would require a seemingly excessive time for deposition of the abundant chert of the Isabel-Eylar area.

The typical lens-form of chert bodies has been ascribed by Rudeman and Wilson (1936) to deposition in small basin-like depressions, the activity of siliceous organisms being confined to the depression. This concept does not satisfactorily account for the overlap of chert lenses and their duplication horizontally and vertically in the sequence. A preferable hypothesis is to suppose that these lenses are penecontemporanous, in the sense that they resulted from diagenetic redistribution of a freshly deposited veneer of radiolarian skeletons (like present day ooze). By simple gliding or by currents, this material could accumulate in the irregularities of the basin of deposition. The typical small- and large-scale contortions in the chert beds could be also explained by movement in a semi-lithified state.

In summary, silica for the small lenses of chert associated with greenstones could have been contributed mainly through inorganic processes in the neighborhood of the volcanic vents, whereas silica for the lenses with abundant radiolaria and iron and manganese oxides can be mostly accounted for through organic processes and the aggregation of widely distributed oozes into lenses. The ultimate source of silica, even for the radiolarian lenses, could have been mainly volcanic springs.

Sedimentary Structures

Sedimentary structures, as discussed here, include depositional and contemporaneous deformational features. These features appear chiefly in the siltstones and the fine-grained sandstones of the lower unit. Such structures have been described elsewhere by many authors, but as they have not hitherto been reported in the Franciscan sedimentary rocks (except for mere mention by Huey, 1948, and Maddock, 1955), it seems worthwhile to give a brief summary of their main characteristics.

The bedding planes of the fine-grained sandstones, siltstones and shales are broadly parallel, at least over the limited distances along which the beds can be traced. In view of the degree of contemporaneous deformation and the involved structures present within the beds, the undeformed character of the major bedding planes is the more notable. Between these parallel or semi-parallel planes a variety of internal structures is found.

Such structures, because they are different in character, magnitude and association from those of near shore deposits, have been called "resedimented" structures by Migliorini (after Kuenen, 1956) and ten Haaf (1957). These and other authors ascribed the structures to turbidity currents.

Conveniently, these structures can be divided into those related to direct deposition, "depositional structures", and those related to contemporaneous deformation before lithification, "deformational structures".

Depositional Structures

Bedding. Most of the siltstones and the fine-grained sandstones are fissile and flaggy. The layers are easily recognizable in the field because of differential weathering. In thin sections, the layers may be only a few—one to four—sand grains thick, separated by very thin micaceous bands. In the coarse-grained sandstone bedding is often indistinct, so that attitudes are difficult to measure.

Particle alignment is noticeable in the fine-grained and conspicuous in the coarse-grained rocks. Alignment is most frequently shown by unabraded shale flakes of various sizes. These flakes may be so abundant that the term "intraformational" conglomerate is

appropriately applied. Concentrations of flakes occur at the base of sandstone beds, as well as the middle. In one case, the concentration of shale flakes was found at the top of the sandstone bed. Shale flakes have been described in Franciscan rocks by many investigators. Davis (1918a), for example, concluded that the shale flakes were (p. 24) "first hardened and then broken up by some disturbance which occurred at a time when the sand, in which it was embedded, was still unconsolidated", and regarded them (p. 36) "as practically positive evidence of subaerial origin" of the sandstones. This argument has been proved false by the discovery of marine fossils in the Franciscan rocks, together with other evidence. Similar occurrences of shale flakes in the Appenines have been reported by Kuenen and Migliorini (1950), and others. Kuenen and Migliorini described the flakes as unabraded, angular and elongate, and consider them as evidence of transportation in suspension by a turbid flow of high density.

Graded Bedding. Graded bedding is a common feature in many of the fine-grained sandstones and siltstone beds and in a few cases in coarse clastics.

The grain size has a maximum variation from coarse sand to silt- or clay-sized particles. The upper and lower contacts of a graded unit are sharp against the adjoining ones. On the basis of experimental work and field observations, Kuenen and Migliorini (1950) have concluded that graded bedding may result from deposition by turbidity currents.

Flute Casts (Flow Markings) and Load Casts: Flute casts (flow markings) and load casts as defined by Kuenen (1957) are exhibited on the bottoms of the sandstone beds at their contact with underlying shaly or silty layers. They are hornshaped protrusions partially overlapping, ranging in length from a fraction of an inch to 5 inches. Similar types of flute casts were described by Rich (1950) and of load casts by de Sitter (1956). Rich (1950, p. 728) interpreted this feature to be the result of subaqueous scour. De Sitter (1956, pp. 301-302) ascribed load casts to initial sinking of parts of the sand into the underlying mud, followed by slight gliding. Greensmith (1956, pp. 348-351) differentiated between flute and load casts, and considered the former to result from penecontemporaneous movement or flow while the load casts are a direct result of vertical loading.

The flute and load casts in the Isabel-Eylar area were used for determinations of tops and bottoms of beds and for measurements of flow direction.

Other sole markings such as worm tracks are also present.

Figure 7. Load casts at the sole of fine-grained sandstone bed overlying shale bed (lower unit). Graded bedding is recognizable.

Figure 8. Current bedding in fine-grained sandstone from the lower unit. Scale in inches.

Current Bedding. Current bedding is one of the most distinctive features in the siltstone and the fine-grained sandstone. This feature may be easily overlooked on dry surfaces, but becomes prominent on moistened outcrops. A bed with current bedding usually has sharp boundaries against overlying and underlying beds. The current laminae may have steep or low angles, and sometimes are almost horizontal. Truncation is noticeable in all of them.

Current bedding locally shows distortion by penecontemporaneous deformation, but for the most part appears to have resisted minor crumpling.

Deformational Structures

Slump Structures. The introduction of the concept of slump structure is mainly due to Jones (1937).

Slump structures similar to those described by him and other authors (Baldry, 1938, Brown, 1938, and Rich, 1950) were observed in the Isabel-Eylar area. These are confined to the siltstone and the fine-grained sandstone rather than the coarse-grained sandstone. Contortions of different sizes and magnitudes are mostly confined to one bed. Some of these contortions are truncated by the overlying bed; in this case deformation or slumping must have preceded deposition of the overlying bed or beds. In most instances, the contortions are not truncated but are "dragged" toward the under- and over-lying beds indicating that slumping took place after the deposition of a sequence of beds and prior to consolidation. Some of these contortions show large scale shortening but this is compensated by the extension of other laminae in the immediate vicinity.

Major Slumping and Crumpling. Other slump features include a quasi-boudinage structure, formed of lenses of sandstone in bedded siltstone or shale. Also, north of the words "Arryo Boyo" in the central part of the map, acute folding (axial planes in all directions) in a normal sequence of strata can be ascribed to submarine slumping of semi-consolidated beds. These features range in size from small convolute structures described above to bends more than 10 feet in amplitude. Minor faults are also recognized. These large slump structures are similar to those described by Baldry (1938), Brown (1938), Rich (1950) and Potter (1957). Such crumpling can account for the complex structure in some places in the Isabel-Eylar area (especially in the upper part of the lower unit) and also for the differences in the attitudes of beds over short distances.

Sandstone Dikes. Sandstone dikes ranging from half an inch to 1½ inches wide and up to a foot long, are noticeable in a few places. The enclosing sandstone or siltstone shows minor dragging against such dikes.

Figure 9. Major submarine crumpling shown by this acute fold in an upright sequence. No intense deformation or shearing has been noticed in the adjacent localities.

Interpretation

The sedimentary structures observed were used to determine the following:

(1) *Direction of Transportation, or Current Direction.* Most of the aforementioned sedimentary structures could be used to determine the direction of transportation or flow of sediments.

The current direction is determined in the field by examining at least three neighboring spots in the same horizon. After rotation of the bed to the horizontal, the inferred trend is recorded. Some complicating factors, however, must be considered here. These factors are whether or not the block in which the measurements are taken has been rotated by submarine slumping or crumpling, and/or by the later intense tectonic deformation. In either case the measured current direction would be different from the original direction. So, it was necessary to find evidence against these defects in each outcrop before recording current directions. A few current directions were recorded and they show a wide scatter in trend. However, there is a general north-south trend. The inconsistency could be accounted for not only by undetected rotation, but also by actual fanning of the current away from the source.

(2) *Mechanism of Transportation.* After the establishment of the concept of turbidity currents, Kuenen (1957, p. 237) referred to features similar to those mentioned above in the following words,

> ". . . under no circumstances are they so richly developed or so habitually combined as under those conditions which prevail during sedimentation by turbidity currents."

There is by now no denial of the importance of such a mechanism. Numerous characteristics of the Franciscan rocks (as the presence of unabraded shale fragments, coarse interbedded conglomerate, submarine volcanic flows, radiolarian chert which is probably of deep water origin), indicate that turbidity currents took a major part in the transportation of the Franciscan sedimentary debris.

(3) *"Top and Bottom" Determination.* The sedimentary structures were helpful in determining the tops and bottoms of beds, that is whether the sequence in a structurally complicated area like this one is upright or overturned. These sedimentary features were used successfully in a large part of the lower unit.

(4) *Type and Extent of Environment of Deposition (Shelf, Slope or Bottom).* Sedimentary structures help in deciphering the type of depositional environment in places where no other indication (as fossils) is available.

Greenstone

Greenstone is a field term applied to altered aphanitic igneous rocks of green or dark greenish-gray color. The term has been applied by many previous authors

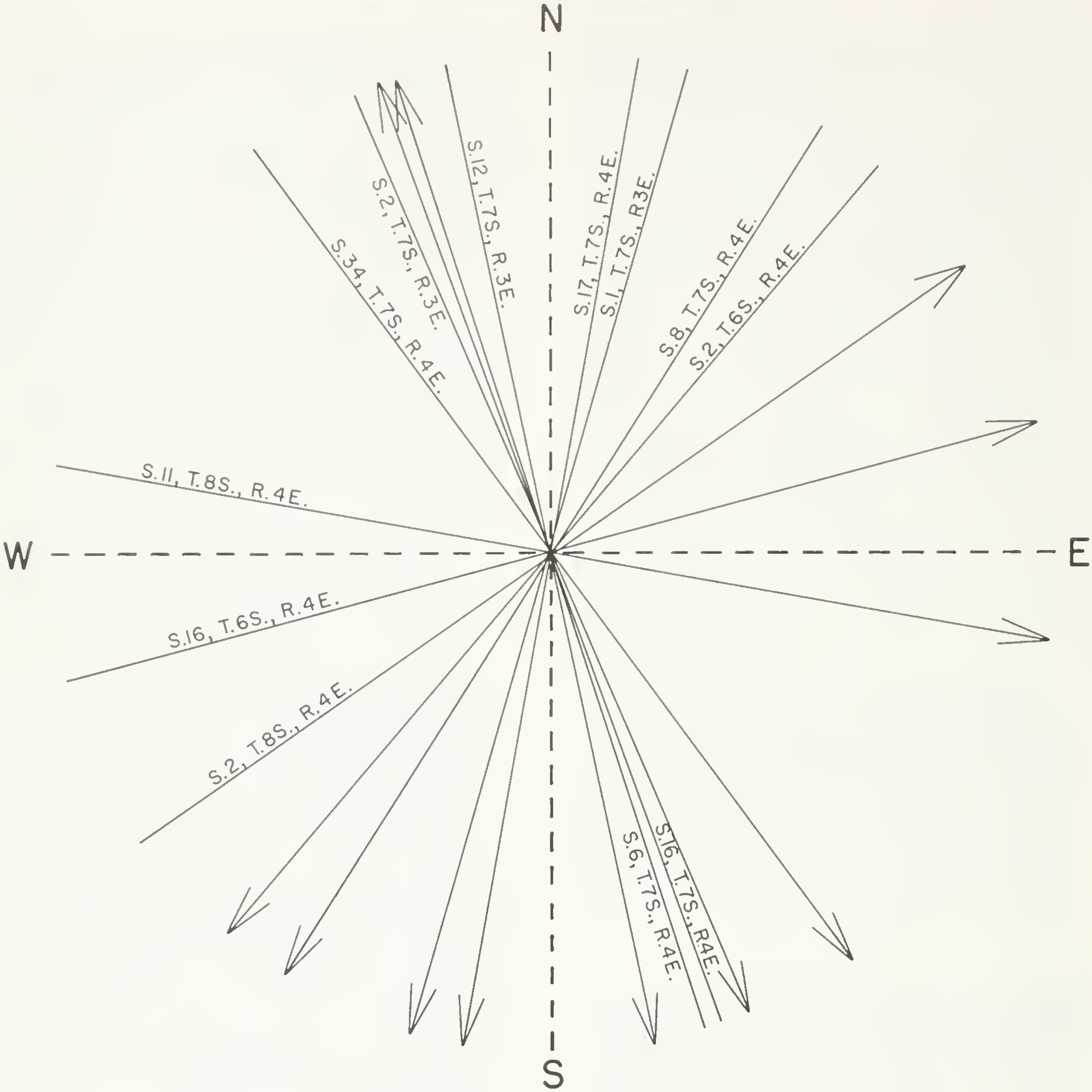


Figure 10. Determined current directions and their locations in the Isabel-Eylar area.

to diabase, basalt, and spilite in the Franciscan formation.

Some of the greenstones are in plug-shaped masses as at Round Mountain; others are lenticular in masses of variable dimensions ranging in area from 10 square feet to more than a quarter of a square mile, like the one west of Sugar Loaf. In all cases, the greenstones show differential movement along their contacts with the adjoining rocks. They are usually surrounded by gouge and sheared sandstones. Pillow structure is present in a few places. At Seeboy Ridge, and at the Jeep trail along Pyramid Rock, individual pillows contain amygdules that decrease in number and size inward. Chert is included among the pillows or in layers within the greenstone mass, as along Mt. Hamilton Road near a spring.

The pillow structure and the association with chert are indicative of submarine eruption; the abundant amygdules indicate extrusion or intrusion at shallow depth.

The examination of 14 thin sections of these greenstones disclosed the following varieties: three basalt

and diabase, seven spilites, three hornblende gabbro, and one altered palagonitic breccia.

The basalt and diabase are here differentiated on the basis of grain size and texture (specific gravities determined range from 2.85-3.19). Intersertal and amygdaloidal textures are common in the basalts. Mineralogically, the basalts are formed of augite, calcic plagioclase (labradorite and bytownite), and ilmenite with chlorite and other alteration products. Pigeonite with $2V = 35°$ is present. The plagioclase shows alteration to clay minerals or to lawsonite. Lawsonite was recognized in all thin sections as long prismatic laths, mainly developed in the plagioclase and groundmass. The amygdules are filled with calcite, chlorite, or albite.

Spilite refers to albitic rocks related to diabase, basalt, or felsite (Dewey and Flett, 1911). The albite crystals are mostly clear, and they are thin and are embedded in a cryptocrystalline or microcrystalline mesostasis. Chlorite, epidote, ilmenite, leucoxene, sphene, lawsonite, are also present. Amygdules and varioles are abundant.

Associated with some spilites and a few of the basalts and diabases are angular masses or inclusions of coarse-grained hornblende gabbro. The greenstones show sharp chilled margins against the gabbro. These masses occur in many localities in the Isabel-Eylar area. The hornblende gabbro mass of Isabel Creek and that of Seeboy Ridge are the biggest. Gabbro inclusions have been reported by Huey (1948) in the Tesla quadrangle. He considered them to be the result of autobrecciation of deep seated hornblende gabbro. A sill of hornblende gabbro is described by Briggs (1953) in the Ortigalita quadrangle.

The hornblende gabbro inclusions are generally more altered than the surrounding rocks. Where glaucophanized, the gabbro shows more glaucophane (in the hornblende) and lawsonite (in bytownitic plagioclase) than the surrounding greenstone.

The greenstones and also the neighboring sandstones are dissected by veinlets of one or more of the following minerals: quartz, albite, lawsonite, prehnite?, jadeite, chlorite, calcite, and in a few cases glaucophane. Some of these veins are as much as a foot thick.

There is a striking similarity between these greenstones and those described in other areas of Franciscan rocks in California and those elsewhere associated with geosynclinal sediments. Excellent treatments of the origin of this kind of rock are found in many publications, including Dewey and Flett (1911), Gilluly (1935), Reinhard and Wenk (1951), Turner and Verhoogen (1951), and Amstutz (1954).

Theories on the origin of the spilites are grouped into two categories: those relating these rocks to primary crystallization and those relating them to metasomatism, either by residual magmatic fluids (autometasomatism) or by sea water in the environment of deposition (Turner and Verhoogen, 1951, p. 207-212). The evidence for albitization in some of the associated basalts and diabases, as well as for the introduction of soda-rich solutions to form veinlets, favors metasomatism. However, it is important to determine whether the albite in the spilite and in the veinlets are genetically related. Some of the albite-quartz veins in the Isabel-Eylar area not only cut the spilite but also the metamorphic rock, showing that introduction of some soda may have been later than the formation of spilite and glaucophanite.

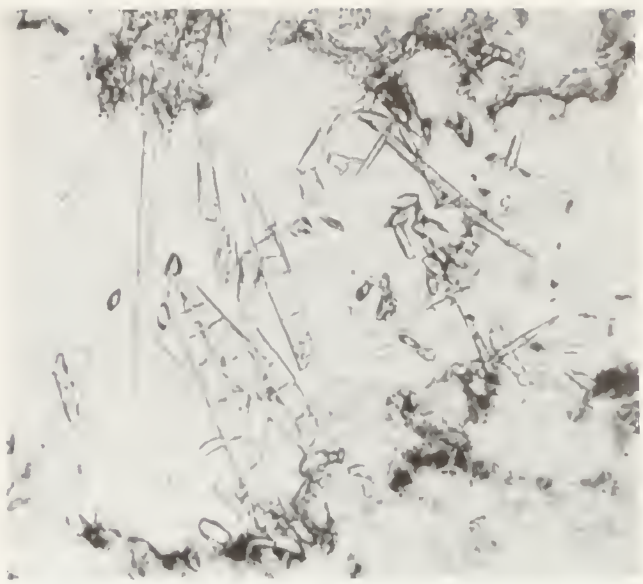


Figure 11. Photomicrograph of lawsonite-quartz vein in sandstone. No intense alteration or shearing was noticed in this sandstone. x120.

Serpentine and Related Rocks

Serpentine and related rocks are present mainly in five places in the northern part of the Isabel-Eylar area. The largest mass, in the eastern portion of the area, is the extension of the "Red Mountain" serpentine and ultramafic mass (Mt. Boardman quadrangle). The northern serpentine mass is the extension of the large body in the Tesla quadrangle (Huey, 1948). Other small masses are shown on the map. The serpentinized masses are buff yellowish-green to dark green in color. They are located in areas with recognizable shearing and structural deformation. They show evidences of "cold intrusion" with no thermal or contact effect on the surrounding rocks. Metamorphic rocks were found in contact with serpentines in only a few places. The masses are formed of serpentine and partly serpentinized dunite showing protoclastic texture. Antigorite and olivine are the main minerals. Chrysotile is found in veinlets especially near the border of the masses. Magnesite pods and chromite lenses are present in the eastern mass.

Glaucophanite and Jadeitite

Glaucophanite, as used by Brouwer and Egeler (1952) and Miyashiro and Banno (1958), designates a

rock that contains glaucophane as one of the main constituents. In the same sense, jadeitite is used here for a rock essentially constituted of jadeite.

Glaucophanite: Glaucophanite is widely distributed in the upper part of the lower unit in outcrops ranging from 10 square feet to more than 2,000 square feet. Its extension in depth is unknown and its contacts with the surrounding rocks are usually sheared or covered. Mineralogically, the glaucophanites of California have been described by many authors (Bibliography in Taliaferro, 1943a, and Borg, 1956). Similar types are recorded from other parts of the world: the Alps, Corsica, Turkey, Japan, New Caledonia, Indonesia, etc.

Fifteen thin sections of the different varieties of glaucophanites from the Isabel-Eylar area were examined. These varieties show great similarities to those described by Borg (1956). They are either massive or schistose.

The massive glaucophanites are widespread; in some cases they are associated with eclogites, in others no relation was detected. They are mostly similar to greenstones in their relation to the surrounding rocks; the metamorphic mass of Sugar Loaf has the same shape as the greenstone of Round Mountain.

Some of those massive glaucophanites show a transition to the eclogites as a result of retrogressive metamorphism of the latter to produce the glaucophanite (Borg, 1956). In many instances, there is an apparent zoning in the eclogites and associated glaucophanites. The eclogite, in the center of the mass, is formed mainly of stumpy crystals of omphacite and a few garnet crystals. This is followed outward by a zone of glaucophane, lawsonite and garnet. The glaucophane is intermingled with the omphacite of the core and increases outward while the garnet is partly or wholly replaced pseudomorphically by chlorite. The outermost zone is an association of actinolite, muscovite, lawsonite, sphene, epidote, ilmenite, and leucoxene with minor glaucophane. Actinolite may dominate to form an actinolite schist with clots of coarse crystalline actinolite. Although these three main zones are present in many localities in the area, they are best exemplified in the area on the map near the letter "H" marking the cross-section lines, in the south-central part of the area. Outside the three zones, the surrounding graywacke shows shearing and the development of chlorite, muscovite, and some epidote and sphene. Lawsonite is abundant in these sandstones as a partial replacement of the plagioclase grains. Jadeite is sometimes recognizable in thin section, but more often is only detectable in the heavy mineral fraction. The exact mutual relation of altered graywackes to the eclogite-glaucophanite zones could not be established with certainty.

Some non-schistose glaucophanite masses show no determinable relation to eclogites. All the above-mentioned minerals are represented except for the pyroxene (omphacite).

Mineral assemblages present in the eclogites and the glaucophanites are:

Omphacite, ilmenite
Omphacite, ilmenite, garnet, late albite
Omphacite, garnet, chlorite, muscovite, ilmenite, leucoxene, sphene
Glaucophane, garnet, sphene, lawsonite, epidote
Actinolite, sphene, pumpellyite
Actinolite, lawsonite, epidote

Through analyses, Borg (1956, p. 1568 and p. 1575) found that eclogites and glaucophanites correspond in composition to basic igneous rocks, basalts. But although the glaucophanites associated with the eclogites can be inferred to have resulted by retrograde metamorphism, the mode of origin of these eclogites could not be deciphered.

The other type of glaucophanite is the schistose variety. This, from field evidence and mineralogic constituents, is meta-chert and meta-siltstone or meta-sandstone. Gradation to unaltered chert, and relict banding were observed. The schistosity is approximately parallel to the attitude of the surrounding rocks.

Mineral assemblages of these rocks are:

Quartz, stilpnomelane, garnet, chlorite, muscovite
Quartz, glaucophane, crossite, garnet, chlorite

The study of the glaucophanites and the incipient development of their minerals in other rocks shows a selectivity in the development of these metamorphic minerals, controlled by the mineralogic and chemical composition of the metamorphosed rocks. Thin-section examination of a hornblende gabbro in contact with finely crystalline spilite, shows the stout prisms of lawsonite in plagioclase crystals, and shreds of glaucophane along the cleavage planes of the hornblende crystals. No glaucophane is present with lawsonite in the

Figure 12. Photomicrograph of spilite in contact with hornblende gabbro, showing chilled margin, replacement of hornblende by glaucophane and development of lawsonite in plagioclase. x32.

plagioclase crystals. The relatively low abundance of ferromagnesian minerals is reflected by the rarity of glaucophane in the adjacent spilite. It is important to note that the contact of spilite with the gabbro is chilled. A further step in metamorphism is shown where the gabbro is changed to a mass of glaucophane, lawsonite and sphene, while the spilite contains pumpellyite, lawsonite and minor glaucophane.

Another example of this selectivity is presented by the meta-chert and the interbedded meta-pelite. The chert band is altered to quartz, stilpnomelane, chlorite, garnet, and the pelite to quartz, glaucophane, garnet, chlorite, muscovite. A sharp contact between the two is revealed by field and thin section studies.

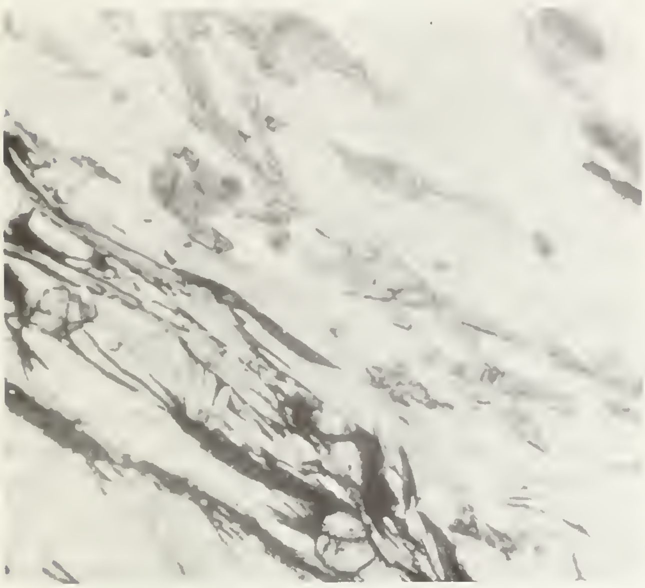


Figure 13. Photomicrograph of meta-sedimentary rock, showing sharp contact between glaucophane, crossite, garnet, sphene, quartz schist, and stilpnomelane, chlorite, mica, sphene, garnet, quartz schist, presumably representing meta-pelite and meta-chert (in contact) respectively. x32.

These features show how the original composition of the parent rock controls the type of minerals developed. In the metamorphism of a graywacke, lawsonite is developed in the plagioclase and in the matrix. Glaucophane is seldom found with lawsonite in plagioclase, but may be present in the matrix and in shale flakes. The reverse is true for jadeite, which occurs within the plagioclase together with lawsonite.

With regard to the origin of the glaucophanites, two schools of thought have existed, one advocating soda-metasomatism, the other, more reconstitution of the rock. More and more evidence, through analyses, is accumulating for the latter viewpoint (Brouwer and Egeler 1952, Borg 1956, and others).

Any theory to be applied to the origin of the massive glaucophanites in the Isabel-Eylar area should take into consideration the following features:

a— Their spotty occurrence.
b— Their similar mode of occurrence to greenstones.
c— Abundance of glaucophanites and eclogites with greenstone.
d— Similarity in chemical composition to unaltered basic igneous rocks.
e— Incipient development of glaucophane, lawsonite, etc., in greenstones.
f— Development of meta-chert adjoining "meta-greenstones".
g— The insignificant development of glaucophane in the sandstones.

In summary, it may be concluded, with considerable conservatism, that there is evidence of reconstitution of rock to form glaucophanite either through retrogressive metamorphism of eclogite or directly from greenstone. The original composition of the rock governs to a large degree the mineral assemblage that is developed. Greenstones were favorable sites for transformation, with the mobilized Na, Mg, Fe, and other elements leading to the formation of the metamorphic minerals. These constituents may have migrated outside these masses to metasomatize the associated chert and other adjacent rocks. The mode of emplacement of eclogite could not be deciphered. Post-metamorphism introduction of soda is manifested in albite-quartz veins that cross the different metamorphic rocks.

Jadeitite. Jadeitites are abundant with the graywackes of the upper unit, especially those associated with chert lenses in the northern part of the Isabel-Eylar area.

At the beginning of the work, jadeitites could not be easily identified in hand specimens in the field, and without the microscopic study of the first rocks collected, the jadeitites would have been overlooked, as they have been by previous authors. Jadeitites can be identified in the field by their relatively high specific

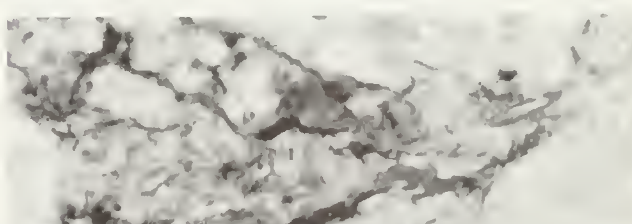


Figure 14. Photomicrograph of jadeitized graywacke from the upper unit, showing development of shreds of jadeite and lawsonite in the plagioclase grain. x120.

gravity (2.76-2.92) compared to that of the graywacke (2.67) and also by the foliation and pistachio-green tint of the rock. These characteristics were of great use in delineating masses of the jadeitized graywacke. Jadeitites in two localities are lenticular and trend roughly parallel to the major structure. Jadeitite was also found more widely distributed but its relative abundance compared to normal graywacke has not been determined and the distribution is not plotted on the geologic map. Generally, jadeitite is found in blocky, highly resistant masses, which are usually greenish in color, foliated (sometimes saccharoidal), and veined with sheared quartz; in many cases the rock breaks into flattened slabs parallel to foliation.

Eight thin sections were examined, in which perfect gradation from normal graywacke to jadeitite was revealed. The sodic plagioclase in the unaltered graywacke was the favorable place for the growth of jadeite and lawsonite. Lawsonite developed as small stout crystals, some of them parallel to the twin individuals in the plagioclase grains. It also developed in the matrix and in the shale flakes of the graywacke. The jadeite, on the other hand, began to form as thin shreds radiating from a center at the border of the plagioclase grain. Some of these increased in width and length to fill the whole grain. Jadeite was not found in the quartz grains. Lawsonite is sometimes present where jadeite is absent, but in many instances, lawsonite crystals cross the radiating jadeite crystals. At this stage of metamorphism, little change occurred in the other detrital constituents and in the clastic texture of the rock. Further development of jadeite in the plagioclase was accompanied by new quartz with normal extinction. Shale fragments show much lawsonite and chorite. Quartz grains show shearing and probable recrystallization and sheared quartz veinlets are abundant. The matrix recrystallized into a mesh of chlorite, mica, and quartz. Glaucophane crystals are found microscopically in very subordinate amount. They probably developed at a later stage than lawsonite and jadeite.

Jadeitized rocks were also found in other parts of the Diablo Range. During a study of the Franciscan sandstones of other quadrangles, including the examination of thin sections from the collection of University of California at Berkeley, jadeitite was found in places where it had not been mentioned in any previous publication. These localities are: Top of Mount Diablo; along Mines Road, Tesla quadrangle; Calaveras Reservoir area, Calaveras Reservoir quadrangle; Morgan Hill quadrangle; Los Aguilas Creek, San Benito quadrangle; Ortigalita quadrangle. Also the heavy minerals of sandstones from these and other localities in the Diablo Range show jadeite that could not be recognized in thin section. Previously described occurrences of jadeite-bearing rocks associated with Franciscan sandstone are: Berkeley Hills; Angel Island, Panoche Valley; North of Valley Ford (Bloxam 1956) and Mt. Boardman quadrangle (Maddock, 1955). Franciscan sandstones examined from other quadrangles in the Coast Ranges of Central California and from the Mendocino National Forest area do not show as high a development of jadeite in sandstones as those of the Diablo Range.

The origin of jadeitite is not at all fully understood. De Roever's hypothesis (1955b, p. 292) is "extreme local variety of regional metamorphism in the glaucophane schist facies". Bloxam (1956) recommended "pressure locally augmented by deformation" as a possible factor in the formation of jadeite, with the composition of the original graywacke also playing a part. Reported chemical analyses of unmetamorphosed graywackes and jadeitites (Bloxam, 1956, p. 493) show great similarity. This is parallel with the similar composition of basic igneous rocks to glaucophanites and eclogites. Both these conclusions are of great importance to show the mutual relation of glaucophanization and jadeitization. Both are found and their minerals are stable under high pressure and low temperature (Yoder, 1950; de Roever, 1955b; Miyashiro and Banno, 1958 with bibliographies). Thus, it appears that the development of glaucophanite or jadeitite is the result of chemical selectivity during metamorphism. This is proved by many observations of glaucophanite and jadeitite found together. Many examples can be cited. One thin section of a greenish sandstone beside a glaucophanite mass from the upper part of the lower unit, shows the development of both lawsonite and jadeite. Its relation to the adjacent glaucophanite could not be determined. Along Colorado Creek a large glaucophanite mass (partly eclogite) adjoins jadeitized graywacke. Furthermore the occurrences of jadeite among the heavy minerals of the sandstones show the widespread presence of this mineral in the upper part of the lower unit. In the upper unit, glaucophanized chert is present to the northeast of the Isabel-Eylar area beside a massive glaucophanite; however, the general scarcity of glaucophanite in the upper unit may be explained by the rarity of greenstone in this unit.

In summary, there was probably selectivity in the development of glaucophanite and jadeitite in the different rocks. The glaucophane and other ferromagnesian minerals could be developed under favorable physical conditions in rocks with a large supply of iron and magnesium ions, as the greenstones, while jadeite could be formed in rocks with a smaller supply of these constituents, as the graywackes.

De Roever (1956) came to the conclusion that pre-Mesozoic regional metamorphism is characterized by biotite, chlorite and green hornblende while post-Paleozoic regional metamorphism has developed lawsonite, glaucophane, and stilpnomelane due to what he considered to be decrease in the steepness of the geothermal gradient in post-Paleozoic times. He therefore regarded lawsonite as a critical index mineral for

post-Paleozoic regional metamorphism. Following these ideas, jadeite can also be added to these index minerals for post-Paleozoic regional metamorphism.

Provenance and Conditions of Deposition

The mineralogic and lithic assemblages of the sandstones and conglomerate of the Isabel-Eylar area require a source area with abundant keratophyres, albite granite, granodiorites, and metamorphic rocks together with some sedimentary rocks. Rocks occurring in two main regions are indicated as the most important contributors to the Franciscan sediments in this area as well as in central and northern California (Part II of the author's Ph.D. dissertation). Data confirming this conclusion are summarized in Table 2. These two regions are the Klamath Mountains and the Santa Lucia Mountains. The Klamath Mountain suite of rocks includes a thick sequence of Paleozoic keratophyres, spilites, andesites, basalts, and metarhyolites, with chert, other sediments, metamorphic rocks, and plutonic igneous rock of albitic type; also early Mesozoic sediments (Diller, 1908; Kinkel, Hall, and Albers, 1956). The Sur series in the Santa Lucia Mountains includes charnokites, granites (with albitic plagioclases) amphibolites, etc. (Reiche, 1940; Wilson, 1942 and Compton, 1957). The Klamath Mountain suite of rocks provided most of the sediments. By establishing this fact on the basis of fragmental constituents similar to these rocks, the hypothesis that an unknown land mass was present to the west (Taliaferro, 1943a) of the trough of deposition is unnecessary. The provenance seems to have been to the east of the trough of deposition, parallel to the Sierra Nevada and possibly centered at the present position of the Klamath Mountains. Other sources could have existed as land masses or islands to the south of the area studied, for example, the Santa Lucia Mountain area (or Salinia as designated by Reed (1933)). These data are thus consistent with Crikmay's idea (1931) of the presence of an eastern land mass called Jurosonora (or Mohavia according to Reed, 1933) that extended from Mexico into southeastern California and southern Nevada.

The Klamath Mountain suite of rocks provided most of the sediments, while the Santa Lucia suite probably contributed only partly to the area and generally to the Diablo Range site. The unstable character of the chief constituents of these sandstones and the general freshness of the plagioclase point to rapid erosion. The theory that turbidity currents were the main transporting agent already has been discussed.

The Franciscan sediments were supplied to an elongated trough that extended along the continental margin by turbidity currents while fine detritus was continuously deposited by other means of sedimentation. The transportation of the sediments was largely parallel to the length of the trough. This fact has been established in the Isabel-Eylar area, and in the Pacheco Pass and Petaluma quadrangles by measurements of current directions. Presumably the general slope of the Franciscan trough was from north to south. Currents started either on one end (as in many present-day and old troughs elsewhere; see Emery, 1956; Kuenen, 1956; Kuenen and Sanders, 1956; ten Haaf, 1956; Potter and Siever, 1956; Siever and Potter, 1956; and others) or at the side of the trough and, after reaching its base, flowed southward. Thus some reprocessing of the sediments could have occurred. This depositional environment and the transportation of sediments in it affected the maturity of the deposits. Such has been established elsewhere by many authors (Folk, 1951, 1954; Bokman, 1955; Pettijohn, 1949, 1950, 1954, 1957; Sanders, 1956; Carozzi, 1957; Potter and Glass, 1958; and others). As indicated by the detailed study of the Isabel-Eylar area, the trough was a relatively deep one, producing an environment in which radiolarian chert formed during intervals of non-deposition of clastics.

Table 2. Probable Source Rocks for the Franciscan Sondstones

Constituent	Possible source rock types	Probable source area in California
Quartz	Igneous, Sedimentary and Metamorphic	No particular source
Plagioclase (albitic)	Spilite, keratophyres, albite granite, metamorphic rocks	Klamath Mtns., Mt. Boardmon, Santa Lucia granites.
Potash-Feldspar	Acidic plutonic rocks	Klamath Mtns.; Sierra Nevada; Santa Lucia Mtns.
Epidote group and rock fragments	Metamorphic rocks	Klamath Mtns.
Sphene (pink), Gahnite and Hypersthene	Crystalline rocks	Santa Lucia Mtns.
Pink garnet	Crystalline rocks	Klamath Mtns.; Santa Lucia Mtns.
Chert and volcanic rock fragments	Sedimentary and volcanic rocks	Paleozoic section in Klamath Mtns.; West of Sierra Nevada

Because of the doubtful age of the Franciscan formation and the rough determination of its maximum thickness (minimum 10,000 feet in the Isabel-Eylar area and maximum 25,000 feet according to Taliaferro, 1943a), one cannot give a definite rate for the deposition of the Franciscan sediments. Kay (1955), considering Taliaferro's (1943a) data to indicate a high rate of 500 meters (1600 feet) per million years during a total span of 15 million years.

Tertiary Basalt

Basalt covers Franciscan rocks in four main localities, centered in Isabel Valley and probably once forming a continuous sheet. These four localities are: a basalt sheet about 20 feet thick and a small dike located west of the reservoir; the sheet supports the tops of the low hillocks in the flat valley. To the north of the reservoir, beside a hunter's shack, there is another dike 10 feet wide trending NW-SE. Another minor outcrop is near the wind-pump northeast of the reservoir. The fourth and biggest exposure is that on the side of the hill in the central part of the map.

Here the basalt is in contact with Franciscan greenstone, glaucophanite, conglomerate and chert. Contact effects include baking of the conglomerate and fracturing and recrystallization of chert.

The basalt is porphyritic and amygdaloidal. In color, it is gray to dark gray, but in weathered and altered places, it is light brownish or reddish.

In thin section, the basalt shows pilotaxitic, intergranular and amygdaloidal textures. Plagioclase, which is in small laths, is labradorite and bytownite. Pyroxene is mostly diopsidic augite; however, pigeonite is also present as light greenish crystals. Ilmenite and leucoxene are minor constituents. Amygdules are filled with quartz, calcite, chlorite or zeolites. The pyroxenes and plagioclases are altered, chlorite is developed and iron oxides impregnate the rock along many fractures. The chert inclusions in the basalt suffered much recrystallization and small quartz euhedra developed together with augite at the contact. Microflow structures parallel the contact.

The age of this basalt can only be inferred from its position in space. It is younger than the Franciscan rocks and it covers an old erosional surface. It is affected by hydrothermal solutions (probably of Quaternary age) and may be pre-Quaternary. Similarities between this basalt and basalts in nearby areas, as Vallecitos, Pacheco Pass, Wildcat Creek (Anderson and Pack, 1915, p. 106), where the probable age is lower Miocene suggest a Miocene or at least a Tertiary age.

Quaternary Deposits

Quaternary deposits are represented in the Isabel-Eylar area by landslides, terrace deposits, and alluvium and gravels in the main streams.

Landslides of various dimensions are widely distributed in the area. The biggest ones encountered (shown on the geologic map) are south and east of Eylar Mountain. They are characterized by dense vegetation, by intermixing of blocks of different rock types, and by hummocky topography. Other landslides are present along Mocho Creek, where they contain conspicuous metamorphic blocks up to 10 feet in diameter, and numerous small slides are visible along Arroyo Valle and Isabel Creek.

Thick deposits of gravel and alluvium are present in the main valleys—San Antonio Creek, Smith Creek and Isabel Creek. The latter two creeks have cut into an alluvial deposit whose surface is sometimes as high as 10 to 15 feet above the present level of the valley floor, thus forming terraces of irregular outline. At least two levels are noticed in some places.

While the floor of the large Isabel Valley is formed of a thick deposit of transported alluvial material, the mantle of soil and broken rock which covers the uplands is residual. The composition of such soil serves to identify the underlying rocks. The soil is reddish over the serpentine and the mineralized chert and the associated sandstone, but most commonly it is yellowish to light brownish on other sandstones and siltstones.

STRUCTURE

The general picture of the Diablo Range has been termed by Anderson and Pack (1915, p. 108) "a broad anticline which has been subjected to long continued erosion." The Isabel-Eylar area lies astride the complicated zone of folds and faults forming the core of this range. The core, formed of Franciscan rocks, has been subjected to intense deformation during post-Franciscan times. The complexity of structure in the Isabel-Eylar area can be inferred from the complex structural history described in neighboring areas, such as the Livermore region (Vickery, 1924), Tesla quadrangle (Huey, 1948), and in general in the Coast Ranges of California (Taliaferro, 1943b, and Gealey, 1951). The structure in the Isabel-Eylar area could not be determined as readily by field mapping as in these neighboring areas, because of the absence of key horizons in the thick Franciscan units and the difficulty of following major structural features, such as shear zones, for long distances. Folds and faults cannot be accurately dated because of the absence of younger correlatable formations. However, the measurement of dips and strikes over the area reveals the general features of its structure.

The area lies on the western limb of the northwest—striking anticlinorial structure of the Diablo Range. This limb is corrugated with folding and cut by major strike faults.

Among the folds in the Isabel-Eylar area, the Burnt Hill plunging anticline is the most prominent and extensive. It is formed chiefly of the rocks of the upper part of the lower unit. Within the area it extends for more than 6 miles in the northwesterly direction and bends westward against the Eylar Mountain block, but is separated from it by a zone of complex structures. Shear zones cut parts of both its limbs. Other important synclines and anticlines are those comprising the Pyramid Rock and Mt. Isabel region. The principal fold here is a long northwest-trending asymmetric syncline formed solely of rocks of the upper unit which makes up the peaks of this high region. These folds presumably extend into the western part of the Mt. Hamilton quadrangle.

Faults are numerous but difficult to follow. Shear zones, good indicators of at least minor faulting, are widespread over the whole area. Most of the shear zones are narrow (up to 30 feet wide) relative to those described in other Franciscan areas (Bailey, 1946), where they form wide long belts. They are characterized by crumpled, angular, slickensided fragments of different rock types. Good exposures of these shear zones are found along Mt. Hamilton Road and along Isabel Creek. Usually a shear zone is bordered by areas with small-scale fracturing, crumpling and minor

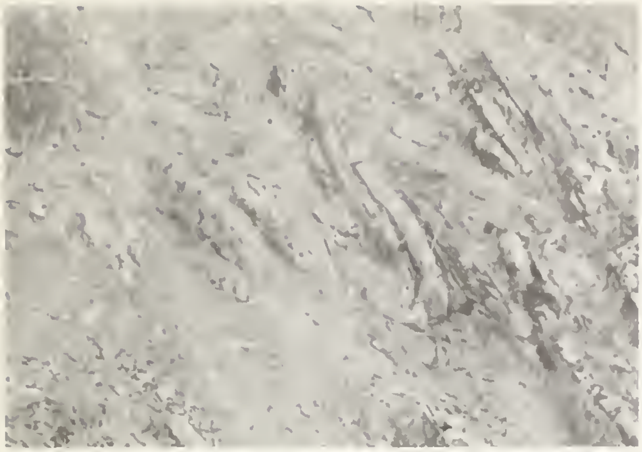


Figure 15. Example of the intense deformation and shearing adjoining some shear zones in the lower unit of the Franciscan formation.

faulting. The sandstone involved in shearing sometimes shows incipient development of foliation, bedding schistosity and crenulations. A few of the faults are topographically expressed by erosional depressions and valleys (as that of Sycamore Creek), but in many other cases no such expression exists.

Major zones of complex structures follow the valleys of Isabel Creek and Colorado Creek. A "zone of complex structure" refers to a belt with indications of displacement, fracturing, shearing, venation and disharmonious attitudes, and local hydrothermal alteration.

Neither the direction nor the magnitude of the net slip along most of the faults could be determined. Along the Colorado Creek zone of complex structure, displacement of at least a few hundred feet is indicated.

In the upper part of the lower unit, there is a recognizable general complexity of structure that can hardly be attributed solely to secondary structural deformation. In good exposures along San Antonio Creek the strata show acute folding and very localized disharmonious attitudes in a continuous upright structural sequence. The folds do not conform with the general structure of the area, and are sometimes truncated by parallel bedding planes. In some instances, they are confined completely without discordance in a series of beds rather than only one bed, with the whole sequence not showing close fracturing as would be expected if the hard quartzitic sandstone was deformed after lithification. These major crenulations were described above in the text, and are probably due to penecontemporaneous submarine slumping.

The major structures are shown on the accompanying geologic map and structure sections.

HYDROTHERMAL ALTERATION

Zones of leaching and alteration are observed locally in the sandstones, siltstones and shales of the lower unit of the Franciscan formation. They are particularly abundant in the belt of inferred complex structure along Isabel Creek and along adjacent belts parallel to it.

The altered rocks preserve their original structures and textures, but are changed in color to greasy white, yellow, and reddish. They show much fracture with mineralization along the cracks. A bright lustrous greenish micaceous mineral is found in veinlets one inch or less in width. Si, Al, Mg, Cr, Fe, Ca, Ti, Ni, V, Mn, Co, B, Sb, Cu, Ba, in order of decreasing abundance, were detected by X-ray spectrographic analysis. In leached sandstones (specific gravity = 2.45) and siltstones, the feldspars are converted in places to clay minerals and the matrix is replaced by iron oxides and hydroxides. Dating the hydrothermal alteration is difficult, but a Quaternary age seems probable because nearby Tertiary basalt has undergone similar alteration and because alteration during the Quaternary has been established elsewhere in the Coast Ranges.

Good examples of similar hydrothermal alteration are reported by Bailey (1946) in the western Mayacmas district, Sonoma County, California, where the alteration is usually associated with sulfide or sulfate hot springs. In the Isabel-Eylar area, mineralized springs are present but those found are not hot. These springs are of two types: A sulfide type and a non-sulfide type. A sulfide spring has a fetid smell and unpleasant taste. Hydrogen sulfide is recognizable. Springs of this type are present at Isabel Creek (sec. 21, T. 7 S., R. 4 E.); in the Horse Valley area near San Felipe Hills (a cattle spring on Stonier's property); at Sulphur Creek; on Eylar Mountain, (sec. 29, T. 5 S., R. 4 E.); and at the mouth of Sulphur Gulch.

Many of these come from fractures, bedding planes or shear zones. A recognizable fetid greasy precipitate can be formed in only one week (Stonier's ranch).

The non-sulfide mineral springs include both acid and alkaline types, but the majority have drinkable water.

ECONOMIC RESOURCES

The Isabel-Eylar area adjoins areas where successful mining operations have been carried on, but within the two quadrangles no deposits of economic significance have been found. Small deposits of manganese, iron, chromite, magnesite and gravels are known to be present.

Pyrolusite, wad and hematite are associated with many of the chert lenses of the upper unit of the Franciscan formation in the northern and western parts of the area. There are some prospecting sites and old workings in some of these lenses. However, no statistical data are available about the produced amounts. According to ranchers, a few hundred tons of manganese ore were produced from some of these

prospects during the Second World War, but none of them is producing at present.

Prospects and trenches exposing small chromite lenses and magnesite veins dissect the serpentine mass to the east of the area. No production has been recorded.

Gravels in stream beds and chert from small quarries have been used for road construction and pavement.

GEOLOGIC HISTORY

Both the depositional history and the structural history of the sequence in the Isabel-Eylar area are dealt with in this section. For the depositional history, proper data are available. But because of the scarcity of younger formations, the structural history after the deposition of the Franciscan formation is obscure.

From the preceding discussions on the two Franciscan units, three main lithologic groupings were indicated. Their characteristics may be summarized as follows:

Lower unit

(1) Lower subunit: Alternating thinly bedded fine-grained sandstone and siltstone with shale; scarcity of coarse clastics; normal absence of submarine volcanics; abundance of directional sedimentary structures; thickness at least 4,000 feet.

(2) Upper subunit: Alternating thinly bedded fine-grained sandstone and siltstone with shale; presence of coarse-grained sandstone lenses and a very few conglomerate lenses; abundance of submarine volcanic rocks locally associated with chert lenses; abundance of slump structures and major crumplings; thickness 3,000 feet.

Upper unit

(3) Massive bedded coarse-grained graywacke; abundance of conglomerate lenses at base; siltstone less abundant; greenstones abundant at base; chert lenses large and abundant, mostly independent of greenstones; unabraded shale flakes scattered through the clastics; thickness 3,000 feet.

The depositional trough of the Franciscan formation has been variously interpreted by different authors. According to Davis (1918a) the deposits were mainly continental intermingled with shallow water marine facies. This view was abandoned by later investigators who recognized the presence of radiolaria, worm tracks and other marine fossils. Later Crickmay (1931) and Taliaferro (1943a) suggested deposition in a geosyncline to account for the thick sedimentary section, the associated submarine volcanic flows, and the radiolarian chert. In general, they proposed a source area of high relief under semi-arid or semihumid climate with relatively rapid erosion and a high rate of deposition into the Franciscan geosyncline, but their data are inadequate to decide whether this geosyncline was a deep or shallow trough. Radiolarian chert indicates a deep water environment while the coarseness of the graywacke and the presence of conglomerate support shallow water (Taliaferro, 1943a), near shore or continental deposition (Davis, 1918a).

Certain aspects of the previous interpretations of the Franciscan graywackes can be modified in the light of more recent ideas on the nature of deposits formed by turbidity currents. All the features present in the Isabel-Eylar area and those mentioned by previous Franciscan geologists, can be explained by the turbidity current theory which has been developed in the field and in the laboratory by many workers (Kuenen, 1956; Kuenen and Migliorini 1950; Kuenen and Menard, 1952; Natland and Kuenen, 1951; Ericson, Ewing and Heezen, 1951 and 1952; Kuenen and Sanders, 1956; Carozzi, 1957; SEPM, Sp. Pub. 2, 1951; and many others). According to this theory, sedimentation takes place chiefly by slides of soft, water-filled sediments from the "shelf" or "slope" to the "bottom" of the depositional trough; the slides developing into turbid flows of silt and mud as they move. The type of material deposited, then, is characteristic of environments other than the actual site of deposition, hence the great differences in interpretation.

In the Isabel-Eylar area, the lower unit shows the following features that may provide a clue to the nature of the sedimentary processes forming them:

(1) Regularly bedded strata with abrupt alternation of coarse and fine grain size, many showing gradational bedding. This could not be easily accounted for by an alternating supply of coarse and fine-grained material. An explanation for such a cyclic sequence can be found in the idea described by Kuenen and Migliorini (1950). The normal sedimentary cover of the sea bed below the continental slope is represented by fine-grained shale and siltstone beds. On the other hand, the equilibrium of sand and mud on the continental shelf-margin is periodically disturbed. This results in widespread slumping and the formation of turbidity currents which spread out beyond the slopes and redeposit their graded load over the shale deposited by other sedimentary processes further away.

(2) Development of small current bedding, flute markings, etc., and absence of ripple markings: These structures indicate the action of a current flow. Current bedding, contrary to older ideas, does not require a definite depth for its formation. According to Bailey (1930), it is a prominent near-shore feature, while graded bedding is geosynclinal. However, the absence of ripple markings shows lack of wave action at the time of the formation of the sediments. The presence of graded bedding with current bedding is a feature that cannot be explained by normal oversimplified sedimentary processes. These features are ubiquitous in many graywackes, and were developed on a small-scale in the laboratory by Kuenen and Migliorini (1950) and others through the agency of simple flow of material. In addition, they were studied quite extensively in the field by many authors (given above, sedimentary structures) who considered them to be "bottom" deposits carried by turbidity currents, probably in deep environments.

(3) Load casts, convolute and slump structures: These penecontemporaneous features, formed before

the consolidation of the sediments, are characteristic of rapid deposition. The abundance of slump structures with load casts, the scarcity of fossils (especially the absence of benthonic types other than worms) and the presence of some pyrite crystals strongly suggest a poorly ventilated and probably euxenic deep environment.

(4) Large-scale crumpling and crenulation of beds apparently while in a poorly consolidated condition: These features are large-scale crenulations that could not possibly be formed by later folding and shearing because such competent materials would have yielded mainly by fracture rather than by folding. Actually, the crumpling is much more prominent in the upper part of the lower unit, where volcanic activity was well developed than in the lower part of the unit. This suggests that volcanic activity has a genetic relation to the crumpling. The disturbances accompanying submarine volcanic activity perhaps initiated turbidity currents of large size and in large numbers. Similar features of crumplings were considered by Baldry (1938), Brown (1938), Jones (1938) and Rich (1950). They cited good examples for the development of these structures on the slopes of depositional troughs.

To summarize, the described sedimentary characteristics of the lower unit are best explained by a current flow. The flow is regarded as a quick pulsatory flow, in the form of turbidity currents, activated to carry material from the shelf and slope to the bottom of the depositional trough. Deposits formed by normal sedimentary processes, other than turbidity currents, could have persisted all through the depositional history of the lower unit. These are either "diluted" by the turbidites or perhaps are represented by the black shale (possibly of pelagic origin) interbedded with the siltstone and the fine-grained sandstone. As the depositional trough did not favor life, it could represent deep water, a poorly ventilated bottom probably of the euxenic type.

The upper unit presents a different problem. It is coarse-grained graywacke with conglomerate, chert and greenstones present at its base. These sediments are mineralogically similar to those of the lower unit, but contain more relatively unstable minerals, more lithic fragments, and more coarse-grained material. Lenses of coarse-grained graywacke, rare in the lower part of the lower unit, increase in number and size with the advent of volcanic flows, and graywacke gradually becomes the dominating constituent in the upper unit.

In discussing a situation in the Appenines similar to that of the lower unit and upper unit in the Isabel-Eylar area, Kuenen and Migliorini (1950) suggested rejuvenation on land as a means of providing coarser materials rapidly to the new shelf of the trough of deposition. Similar rejuvenation is probable in the Isabel-Eylar area, and was accompanied by submarine volcanic activity.

The abundant fresh feldspar in the graywackes indicates an effective mechanical disintegration and rapid transport to the place of deposition. The common unabraded shale flakes and their orientation indicate they were carried in suspension in a dense current. In other words, the turbidity current hypothesis still can be applied. The presence of coarse conglomerate might be considered as indicative of shallow near-shore conditions, but more likely the conglomerates were emplaced by slides from the shelf. The occurrence of radiolarian chert lenses, the absence of benthonic organisms, and other indications summarized above make shallow water deposition very unlikely.

In summary, except for the coarseness of the clastics, the upper unit provides evidence for dense flows which probably pulsated due to alternating periods of tectonic stability and instability. The stable periods produced a favorable environment for the concentration of radiolarian skeletons diluted only with fine clayey material of pelagic origin. The change of texture and material of the sediments could be caused by changes in the relief of the source simultaneous with the beginning of volcanic activity.

With the aid of the accompanying diagrams the geologic history can be summarized as follows:

(1) On the slope and bottom of the growing Franciscan geosyncline or trough of deposition, silty and clayey sediments accumulated by normal sedimentary processes, while on the shelf relatively coarser and more mature materials were deposited (stage 1).

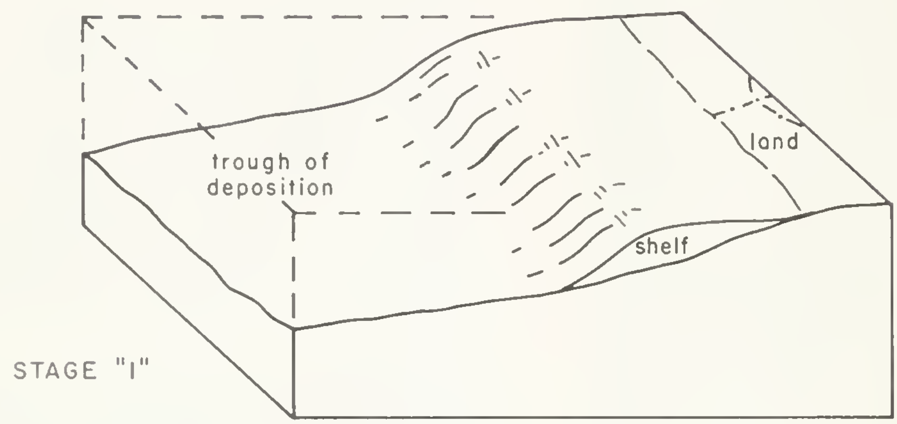
(2) Disturbances on the shelf caused turbidity currents, which carried sandy and silty materials from the shelf and slope to the lower part of the slope and over the bottom to form the fine-grained arenitic sandstone and the interbedded siltstone. Black shale could have formed by normal sedimentary processes as a pelagic sediment, and in the interval between two consecutive turbidity flows. Graded bedding, current bedding, minor slumps and other sedimentary structures developed in the turbidities (stage 2).

(3) With the continuation of the last stage, coarse arenitic sediments could have been developed on the shelf and could have been carried to the environment of deposition by turbidity currents.

(4) The instability in the environment of deposition increased with the extrusion of volcanic rocks and the emplacement of minor intrusions. This volcanic activity caused major slumping in the turbidites, and simultaneous rejuvenation of relief on adjacent land areas supplied coarse-grained sandy material to the environment of deposition. Volcanic flows could also be the cause of the major crumpling and crenulation in the sediments involved. This would increase the complexity of the structure and thereby account for the disharmonious attitudes in the upper part of the lower unit. Near the volcanic masses small chert lenses, mostly of inorganic origin, were formed with some radiolaria (stage 3).

(5) With the advent of volcanic activity and rejuvenation on the land, turbidity currents carried the coarse immature sands developed on the new shelf to the trough of deposition. Pebbles, cobbles and boulders were also carried. Shale flakes are abundant; they are unabraded, and lie parallel to bedding, suggesting transportation by suspension in the turbidity cur-

GEOLOGIC HISTORY



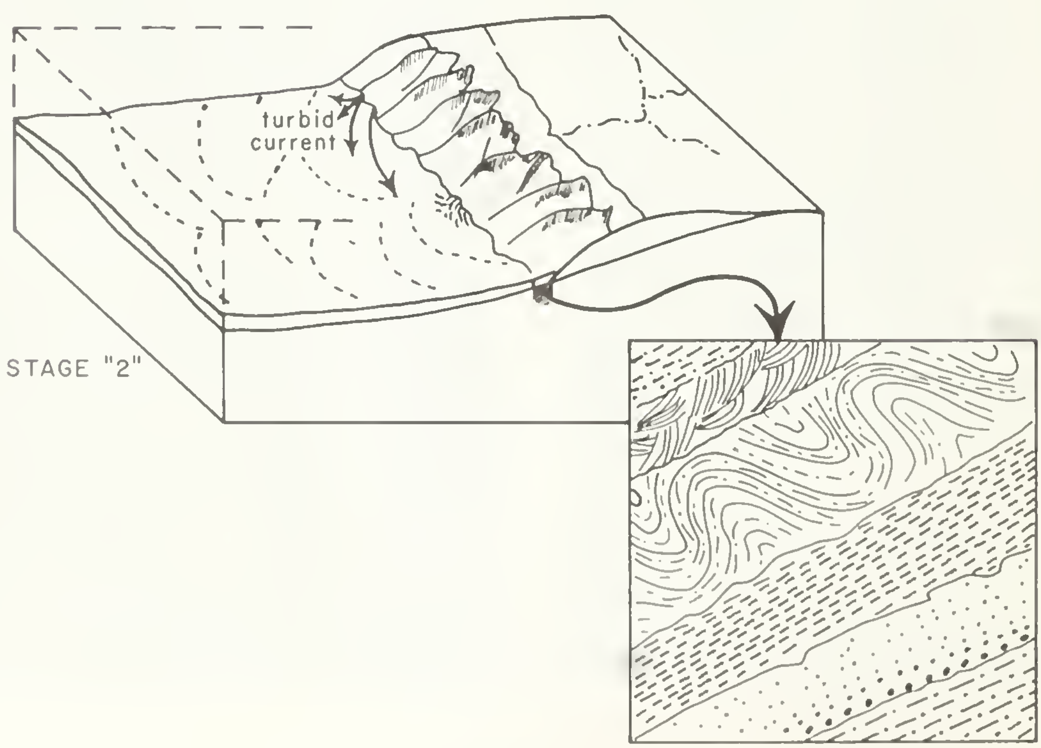


Figure 16.

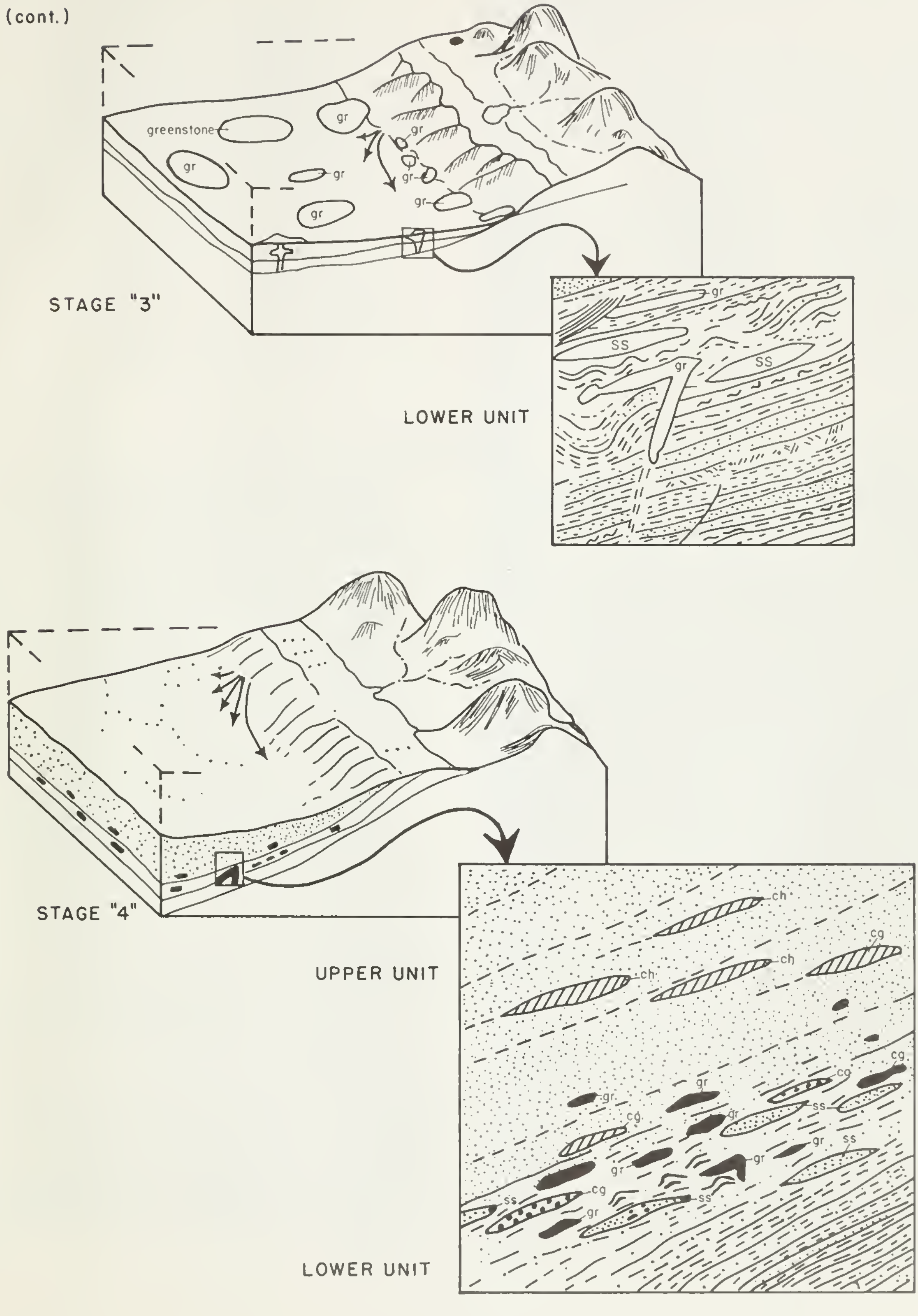


Figure 16 (continued).

rents. Magmatic activity persisted at the beginning of deposition of the upper unit, and then slackened greatly toward its end. In different stages, thin radiolarian ooze, together with inorganically deposited silica, was developed. Silica supply might have been mostly from volcanic springs that carried iron and manganese compounds too. Then, with gliding, the siliceous veneer could have accumulated in the irregularities in the basin of deposition to give rise to the multitude of chert lenses. Absence of much dilution with coarse clastics and the presence mostly of fine clayey material with the chert suggest relatively quiet periods and periodic cessation of turbidity flows. With these intervals of non-dilution, mineralization occurred with the chert (stage 4).

The mineralogic and lithic assemblages of the sandstones and conglomerate require a source area with abundant keratophyres, albite granite, granodiorites and metamorphic rocks together with some sedimentary rocks. Because an assemblage of this sort is found in the Klamath Mountains, they, or their southern extension, are a probable source for much of the Franciscan sediments. The sediments were presumably diluted by materials from exposures of the Sur Series (Santa Lucia Mountains), as is shown by the presence of some of their characteristic minerals in the heavy mineral fraction of the Franciscan sandstones. Current direction shows a roughly north trend parallel to the assumed trough of deposition.

(6) Later metamorphism produced the complex glaucophanites from greenstones, as is indicated by their similar chemical composition and also jadeitites from graywackes. Two stages of glaucophanization are suggested by the presence of glaucophanite cobbles in some of the conglomerate. Serpentinized ultramafic rocks were re-intruded or remobilized, most probably after metamorphism. Complexity of structure was attained by folding of the trough of deposition and afterward by further deformation in several periods of tectonic activity.

(7) Small flows of basalt covered parts of an old erosional surface, probably sometime during the Tertiary. Feeder dikes are present.

(8) Minor leaching and mineralization were caused by hydrothermal activity locally along major zones of complex structure.

(9) The present topography shows uplift of an old erosion surface in fairly recent geologic time.

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BULLETIN 185
PLATE 1

EXPLANATION

SYMBOLS

Contacts
- Known
- Approximate

- Known
- Inferred

plate

———, 1955b, Genesis of Jadeite by low-grade Metamorphism: Am. Jour. Science, v. 253, p. 283-298.

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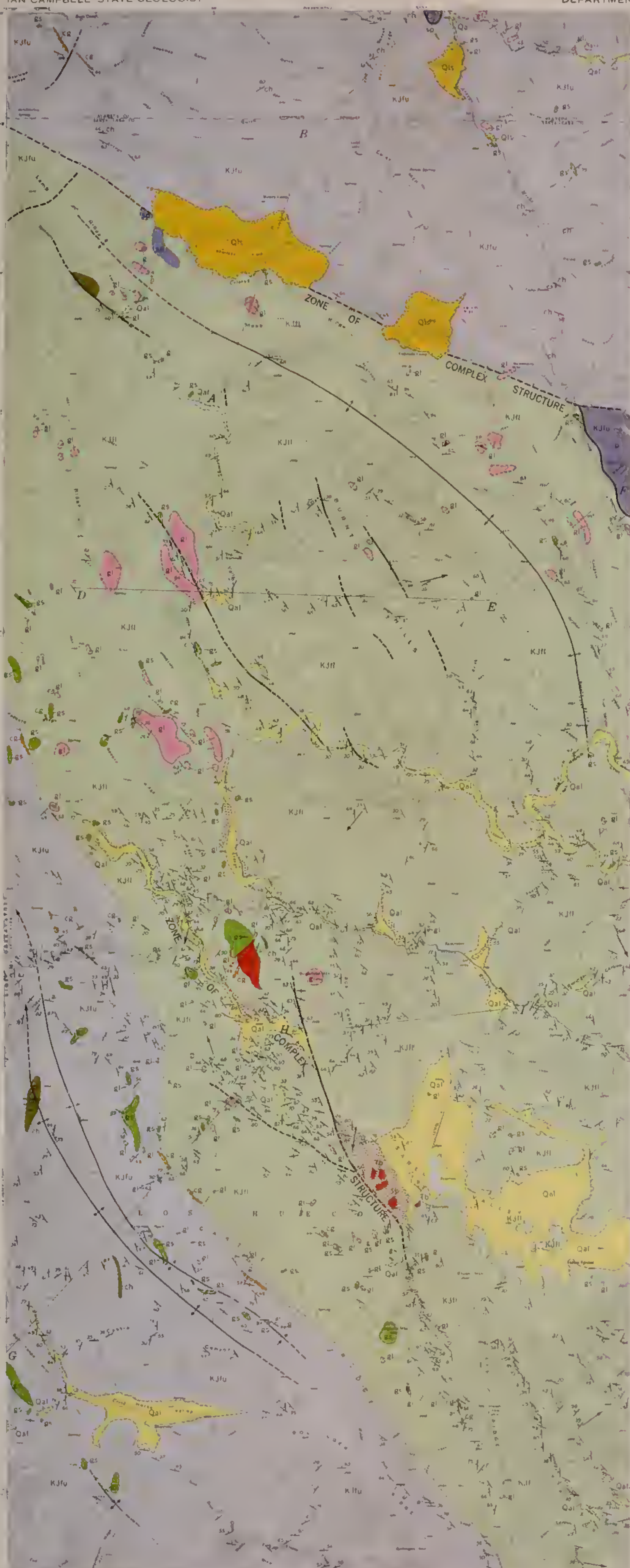
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION



Topographic base mapped, edited, and published by the U. S. Geological Survey

Geology surveyed in 195

GEOLOGIC MAP OF THE EAST HALF OF THE MT. HAMILTON QUADRANGLE, CALIFORNIA

By

EXPLANATION

ROCKS

QUATERNARY
- Qal — Alluvium
- Ql — Landslide

TERTIARY (MIOCENE)
- Basalt

JURASSIC (?)-CRETACEOUS FRANCISCAN FORMATION

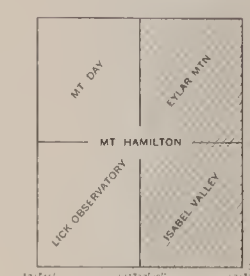
SEDIMENTARY
- KJfu — Coarse-grained sandstone, siltstone, chert (ch), conglomerate (cg) — Upper Unit
- KJfl — Fine-grained sandstone, siltstone and shale — Lower Unit

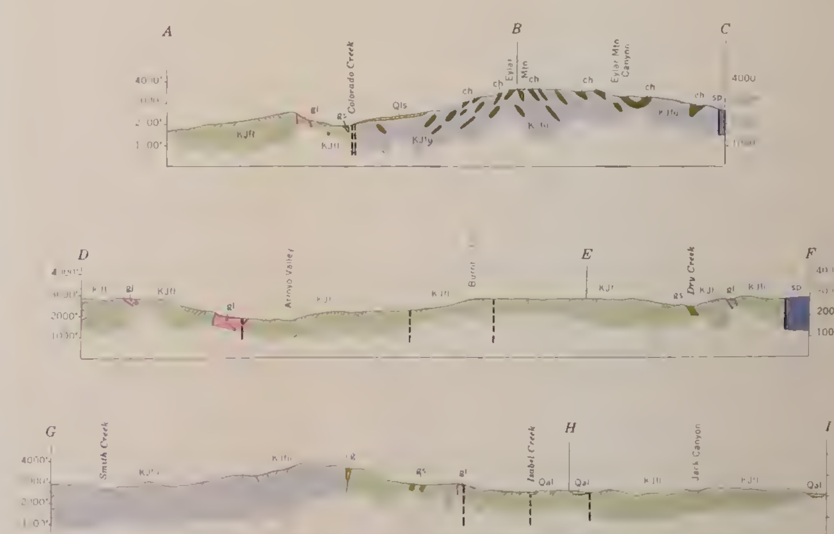
IGNEOUS AND METAMORPHIC
- Greenstone
- Serpentine
- Glaucophanite and related rocks

SYMBOLS

Contacts: Known; Approximate
Faults: Known; Inferred; Doubtful; Concealed
Folds: Axis of Anticline; Axis of Syncline
Strike and dip: Upright; Overturned; Vertical; Foliation
Current direction
Hydrothermal alteration

INDEX OF QUADRANGLES





GEOLOGIC STRUCTURE SECTIONS ACROSS THE EAST HALF OF THE MT. HAMILTON QUADRANGLE, CALIFORNIA

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL